

**IN THE UNITED STATES DISTRICT COURT  
FOR THE NORTHERN DISTRICT OF OKLAHOMA**

STATE OF OKLAHOMA,	)	
	)	
Plaintiff,	)	
	)	
v.	)	Case No. 05-cv-329-GKF(PJC)
	)	
TYSON FOODS, INC., et al.,	)	
	)	
Defendants.	)	

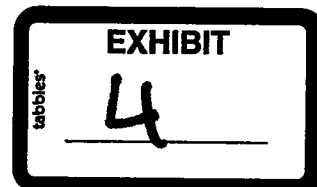
**DECLARATION OF ROGER L. OLSEN, Ph.D.**

I, Roger L. Olsen, Ph.D., under penalty of perjury, hereby declare as follows:

**A. BACKGROUND**

1. Since February 1985, I have been an employee of Camp Dresser & McKee Inc. ("CDM"), an environmental consulting firm. I currently hold the position of Senior Vice President and Senior Geochemist with CDM. My educational background includes a Bachelor of Science degree, with high distinction in Mineral Engineering Chemistry, from the Colorado School of Mines in Golden, Colorado, in 1972 and a Doctor of Philosophy degree in Geochemistry from the Colorado School of Mines in 1979.

2. From 1975 to 1978, I was an instructor in chemistry and geochemistry at the Colorado School of Mines. I taught courses in general chemistry and quantitative analysis. From 1978 to 1979, I was a senior research chemist with Rockwell International at the Rocky Flats plant. I was responsible for evaluating methods to clean up contaminated soil at Rocky Flats and other Department of Defense facilities. From 1979 to 1983, I was a project supervisor with D'Appolonia Consulting Engineers. In 1983, International Technology (IT) acquired the portion of D'Appolonia for which I



worked. At D'Appolonia and IT, I performed many evaluations related to environmental contamination. In 1985, I joined CDM where I continued to evaluate environmental contamination. I have extensive experience in performing environmental investigations and studies, evaluating the environmental fate and transport of chemicals in the environment and determining the cause or source of contamination in the environment. In all, I have worked on or evaluated environmental conditions at over 500 sites. I am the author or co-author of over 120 publications/presentations and over 400 technical reports relating to environmental contamination.

3. In November 2004, CDM was retained by the Oklahoma Attorney General to perform an investigation concerning environmental contamination found in the Illinois River Watershed ("IRW"). I have been CDM's Project Technical Director since inception of the project. In this capacity, I have helped plan and direct a systematic investigation of the environmental contamination found in the IRW. This investigation included collection and laboratory analyses of poultry waste, soils, surface waters, groundwaters and sediments throughout the IRW.

#### **B. EXPERT REPORT**

4. On May 14, 2008, I submitted an Expert Report to the Defendants in the above-captioned litigation (attached hereto as Ex. 1). This Expert Report contains statements, findings, analyses and opinions related to CDM's investigation of the IRW.

5. The following excerpts from my Expert Report contain my true and correct statements, findings, analyses and opinions:

### **“...Hazardous Substances in Poultry Waste**

Assuming the list of Hazardous Substances and Reportable Quantities (table 302.4, 40 CFR § 302.4) includes not only the specific chemical listed but also chemical compounds, chemical forms and chemical combinations of the listed chemical, analyses of poultry waste and literature reports include many hazardous substances including:

- Ammonia (CASRN 7664417)
  - Ammonia and Compounds
- Arsenic and compounds
- Cadmium and compounds
- Chromium and compounds
- Copper and compounds
- Lead and compounds
- Manganese compounds
- Nickel and compounds
- Nitric Acid (CASRN 7786-81-4)
- Nitrogen oxides
- Nitrosamines
- Phosphorus and compounds
- Phosphoric acid (CASRN 7664382)
- Polynuclear aromatic hydrocarbons
- Radionuclides
- Selenium and compounds
- Sodium and compounds
- Sulfuric acid (CASRN 7664939)
- Thiourea (CASRN 62566)
- Unlisted hazardous waste with characteristic of reactivity
- Zinc and compounds

The CAS Registry Number 7723140 refers to elemental phosphorus. This substance does not naturally exist in the environment. However phosphorus is present as compounds in the feed, poultry waste and poultry waste in soils mainly as phosphate ( $\text{PO}_4^{-3}$ ) compounds. As an environmental constituent dissolved in moisture or water (the mobile phase), the exact chemical composition of the phosphate will depend upon the pH of the water. At a neutral pH, the phosphate will exist as dissolved aqueous anions both:  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$ . At the same pH value, these chemical forms and proportions of these chemical forms are identical to the chemical forms and proportions of the listed substance phosphoric acid.”

(Expert Report, Ex. 1, at § 6.4.3.5).

### **“...Pathway Sampling Approach**

The overall sampling approach was to collect and analyze water or solid materials (wastes, soils and sediments) in each major compartment (component) of the environment. The purpose of this approach was to document, if possible, the fate and transport of poultry associated contamination from its origin (land disposal of poultry waste) through each environmental transport step to the ultimate deposition in the sediments and water of Lake Tenkiller. **Figure 6.5-1** illustrates each of the major environmental components. These include (in order from source to final location)

- Poultry waste from the poultry houses, upper right hand corner of **Figure 6.5-1** (samples collected from the poultry houses in the IRW were called litter or facility, FAC, samples)
- Soils from fields on which land application of the poultry waste occurred (samples are called land application locations, LAL, samples)
- Water runoff from fields with waste as a result of precipitation (rainfall) events (samples are called edge of field, EOF, samples)
- Waters from small tributaries in watersheds in which poultry houses exist and waste disposal occurred (samples are called high flow station, HFS, samples)
- Ground water in shallow alluvial materials near streams that may be contaminated as a result of infiltration (rainfall moving through the soil) on waste applied fields (samples were collected using Geoprobe techniques and are called GP samples)
- Ground water from deeper geologic strata (samples were collected from existing homeowner wells and samples are called ground water, GW, samples)
- Water from springs that may represent contaminated groundwater resulting from infiltration on fields (samples are called spring, SPR, samples)
- Water from rivers within the IRW including both small and larger rivers (samples from larger streams at USGS stations are called USGS samples; samples from other locations, both large and smaller streams, are called river stations, RS, or biological stations on the rivers, RBS)
- Waters collected from streams during base flow conditions that represent groundwater recharge (samples from the small tributaries are call HFS-BF; however, all river samples have a designation indicating whether samples were collected during high flow or base flow)
- Waters from Lake Tenkiller (samples from Lake Tenkiller are designated lake, LK, samples)
- Waters from outside the IRW that are reference samples (samples are designated REF – also other designations, see Section 2.13)
- Sediments from rivers in the IRW (samples are designated sediments, SD, samples)
- Sediments from Lake Tenkiller (both grab and core samples were collected and are designated lake sediments, SEDLK or SDLK)

A number of major poultry waste constituents, or parameters, are found in each of the environmental components. Phosphorus (4500PF), total organic carbon (TOC), copper, zinc, potassium, enterococci, fecal coliform, e. coli, total

coliforms, total Kjeldahl nitrogen (TKN), aluminum, iron, estrone, sodium, alkalinity, calcium, arsenic, magnesium, and total dissolved solids were contaminants selected to evaluate in each of the aquatic environmental components. Phosphorus (6020), total organic matter, copper, zinc, potassium, arsenic, calcium, estrone, e. coli, enterococci, fecal coliform, total coliforms, nitrogen, soluble salts, sodium, magnesium, sulfate (SO<sub>4</sub>), and phosphorus (water-soluble) were contaminants selected to evaluate each the solids environmental components.”

(Expert Report, Ex. 1, at § 6.5; Figure 6.5-1, Ex. 2).

#### **“...Distribution of Phosphorus throughout the Basin – Water**

Surface Water: **Figures 6.6-1 through Figure 6.6-4** are spatial representations of the average concentration of total phosphorus (4500PF) for the various sampling locations. The majority of the locations had concentrations of total phosphorus (4500PF) that were greater than the Oklahoma water quality standard of 0.037 mg/L. **Figure 6.6-3** indicates that the highflow surface water locations in Arkansas tended to have higher concentrations than those sampled in Oklahoma. As shown, phosphorus is widespread and pervasive throughout the entire basin with the average concentrations at most locations above 0.037 mg/L and above background concentrations. Particularly see **Figure 6.6-4a** which provides the results of soluble reactive phosphorus at 194 locations collected in August 2006 over a two week period.

**Figure 6.5-2 and Figure 6.5-3**...indicate that the concentration of total phosphorus is highest in the poultry edge of field samples (EOF) and then decreases as the water moves through the various components. The majority of the concentrations of total phosphorus range from 0.6 mg/L to 3 mg/L for the EOF samples. The majority of the concentrations of total phosphorus for the other components are typically lower than 0.1 mg/L. As shown in **Figure 6.5-4** and **Figure 6.5-5**, a very similar trend is seen with the soluble reactive phosphorus (SRP) with the majority of the concentrations for the EOFs ranging from 0.2 mg/L to 1.2 mg/L. The majority of the concentrations of SRP for the other components are typically lower than 0.1 mg/L.

Groundwater: **Figure 6.6-13** is a spatial representation of the average concentration of total phosphorus (4500PF) for the various geoprobe, springs, and well stations. Phosphorus was found in each of these components, with higher concentrations typically found at the geoprobe and springs stations.”

#### **“Summary of Observations**

Poultry waste related contaminants are wide spread and pervasive across the IRW. The poultry contaminant concentrations decrease from the source of the contamination (fields with poultry waste application) to Lake Tenkiller in a logical manner consistent with fate and transport mechanisms. The concentrations

of poultry related contaminants are typically above background or reference concentrations in all the environment components.”

(Expert Report, Ex. 1, at §§ 6.6.1 and 6.6.3; Figures 6.5-2 – 6.5-5, Ex. 3; Figures 6.6-1 – 6.6-4, Ex. 4; Figure 6.6-13, Ex. 5).

**“...Distribution of Phosphorus throughout the Basin – Solid**

**Figure 6.7-1** is a spatial representation of the average concentration of total phosphorus (6020) for the various river and lake sampling locations where sediments were collected. The majority of the river and all of the lake locations sampled had concentrations of total phosphorus (6020) that were greater than 270 mg/kg. The Lake Tenkiller samples shown are for surface grab samples only. Phosphorus is widespread and pervasive throughout the river and lake sediments in the IRW. As shown in **Figure 6.5-19** and **Figure 6.5-20** (introduced in previous section), the majority of the concentrations for the phosphorus in poultry waste ranged from 15000 mg/kg to 26000 mg/kg. There was then a decrease in the phosphorus concentration found in the top two inches of field soils with the majority of the concentrations ranging from 650 mg/kg to 1300 mg/kg. A concentration range for the majority of the river sediment samples was found (299 mg/kg to 693 mg/kg). An increase in phosphorus concentration was observed in the Lake Tenkiller sediments with the majority of the samples ranging from 442 mg/kg to 1400 mg/kg (grab results). These concentration ranges were generally higher than the reference soil which had the majority of the samples ranging in concentration from 174 mg/kg to 407 mg/kg.”

***“Summary of Observations***

Poultry related contaminants are found in river sediments and Lake Tenkiller sediment at concentrations greater than background concentrations. The locations and concentrations are consistent with known fate and transport mechanisms starting at the source locations (i.e., contaminated soils from fields with poultry waste and subsequent runoff during precipitation events).”

(Expert Report, Ex. 1, at §§ 6.7.1.2 and 6.7.2; Figures 6.5-19 – 6.5-20, Ex. 6; Figure 6.7-1, Ex. 7).

“□ The potential major sources of contamination in the IRW (cattle, poultry waste and WWTP discharge) have distinct compositions.

□ The poultry waste, poultry waste synthetic leachates and edge of field samples from fields with poultry waste have significantly higher concentrations than cattle manure synthetic leachates and WWTP effluents of many contaminants including phosphorus, copper, zinc, total Kjeldahl nitrogen and potassium. The very high concentrations of contaminants in the poultry waste should result in observable concentrations in the environmental components of the IRW (waters and sediments).

The distinct compositions of the sources should result in definitive signatures of contamination in the IRW if the sources are major contributors to the contamination.”

(Expert Report, Ex. 1, at § 6.4.1).

### C. RESPONSE COSTS

6. As part of CDM’s investigation of the IRW, the State has incurred costs in connection with investigating and monitoring the presence of many hazardous substances found in poultry waste, including but not limited to: ammonia and compounds; arsenic and compounds; chromium and compounds; copper and compounds; lead and compounds; manganese compounds; nickel and compounds; phosphorus and compounds; selenium and compounds; sodium and compounds; and zinc and compounds.

### D. PHOSPHORUS FOUND IN THE ENVIRONMENT

7. While it is true that phosphorus compounds such as phosphates ( $\text{PO}_4^{-3}$ , etc) are commonly found in the environment, based on my education, training, experience and knowledge, it is uncommon to find phosphorus concentrations as high as CDM has found throughout the IRW. *See, e.g., ¶ 5, supra.*

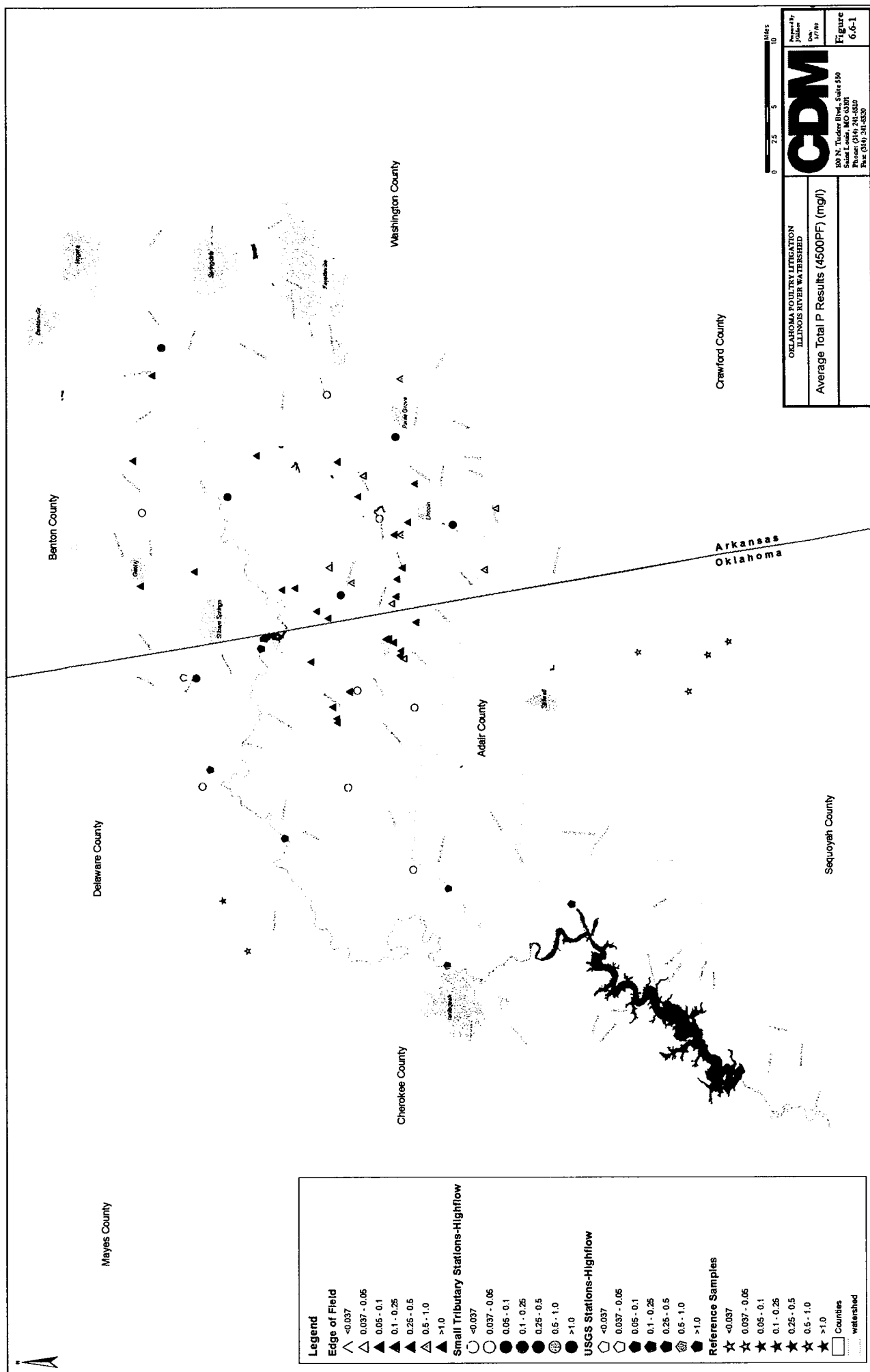
I declare under penalty of perjury, under the laws of the United States of America, that the foregoing is true and correct.

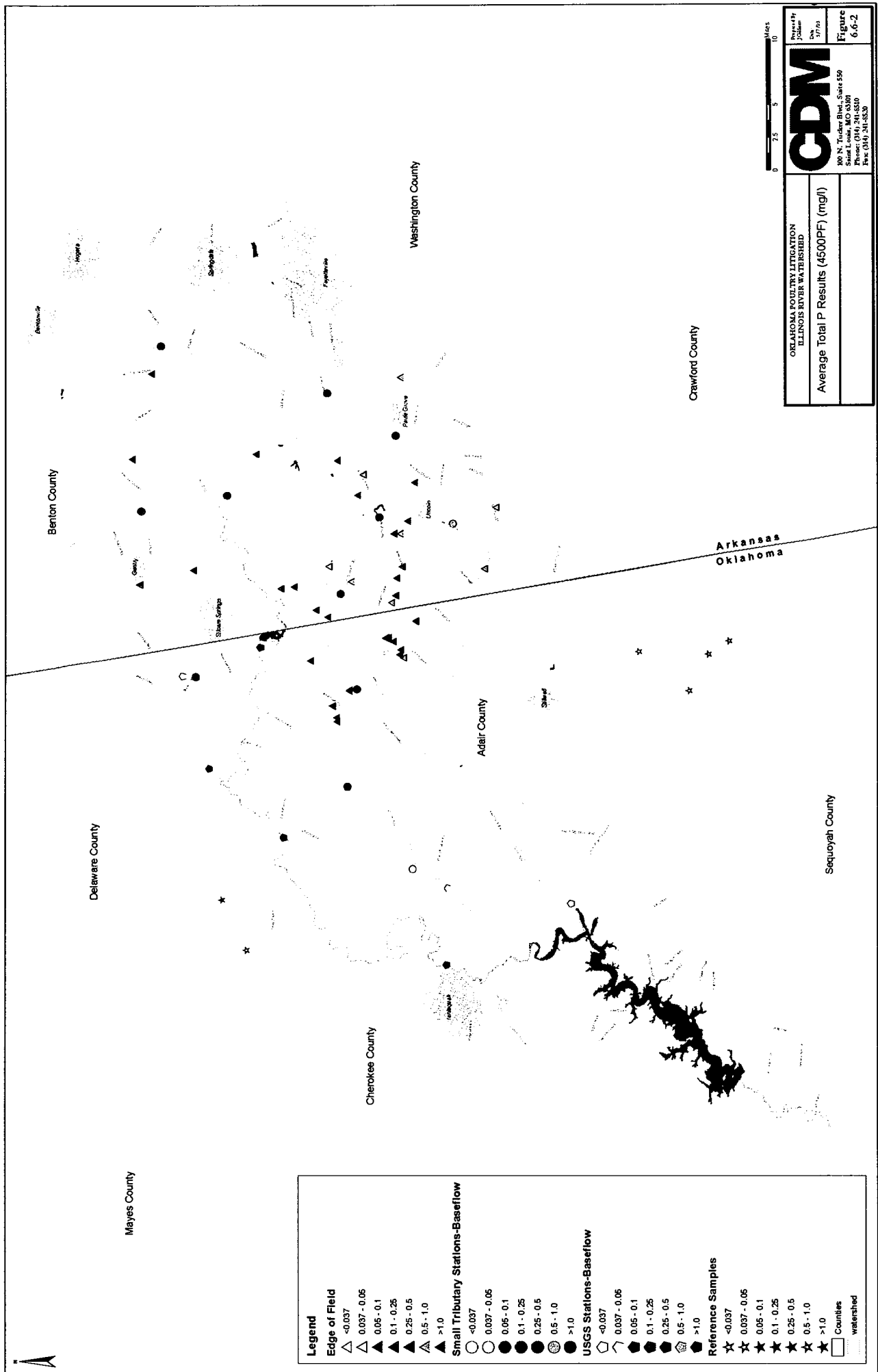
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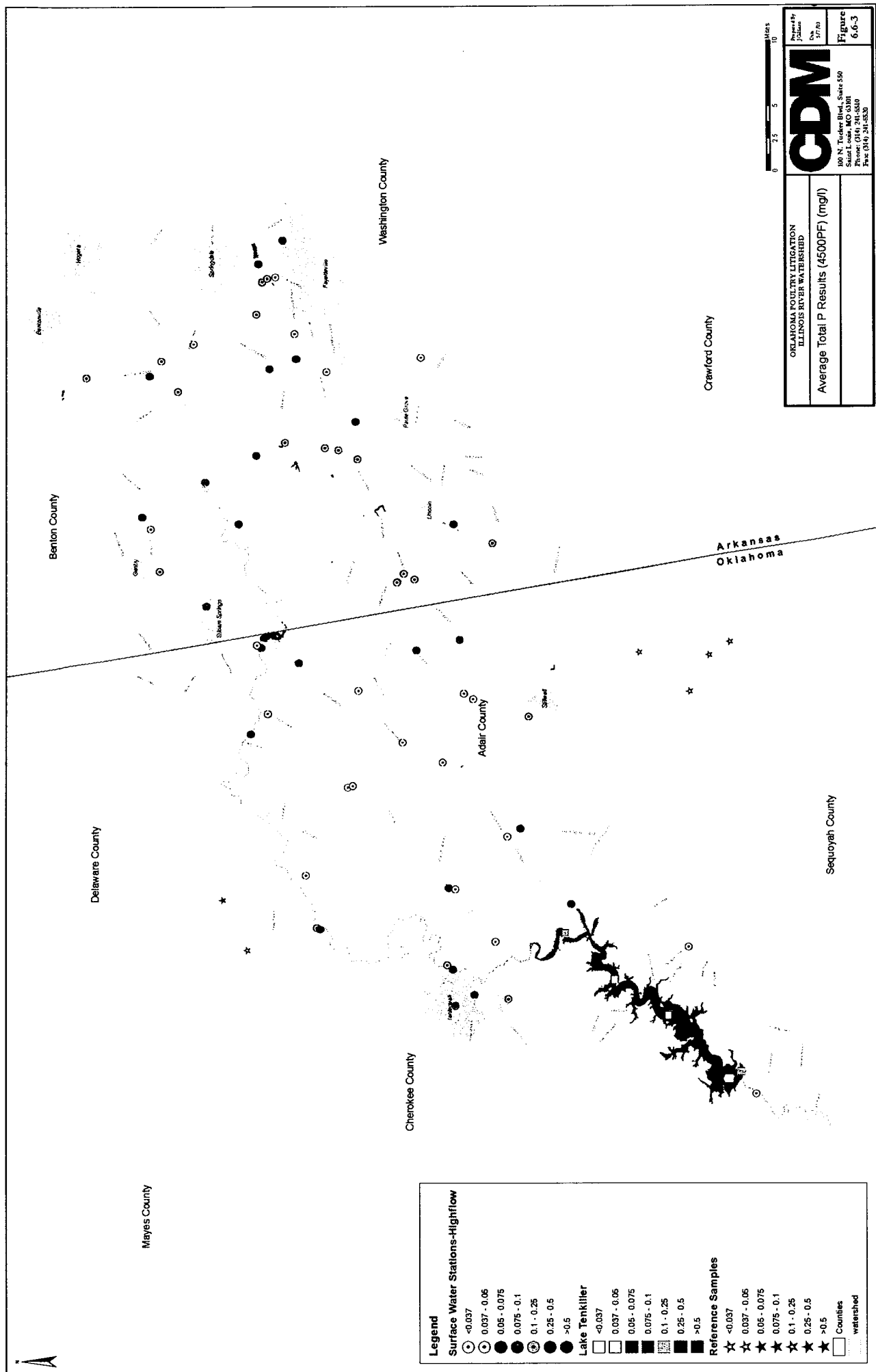


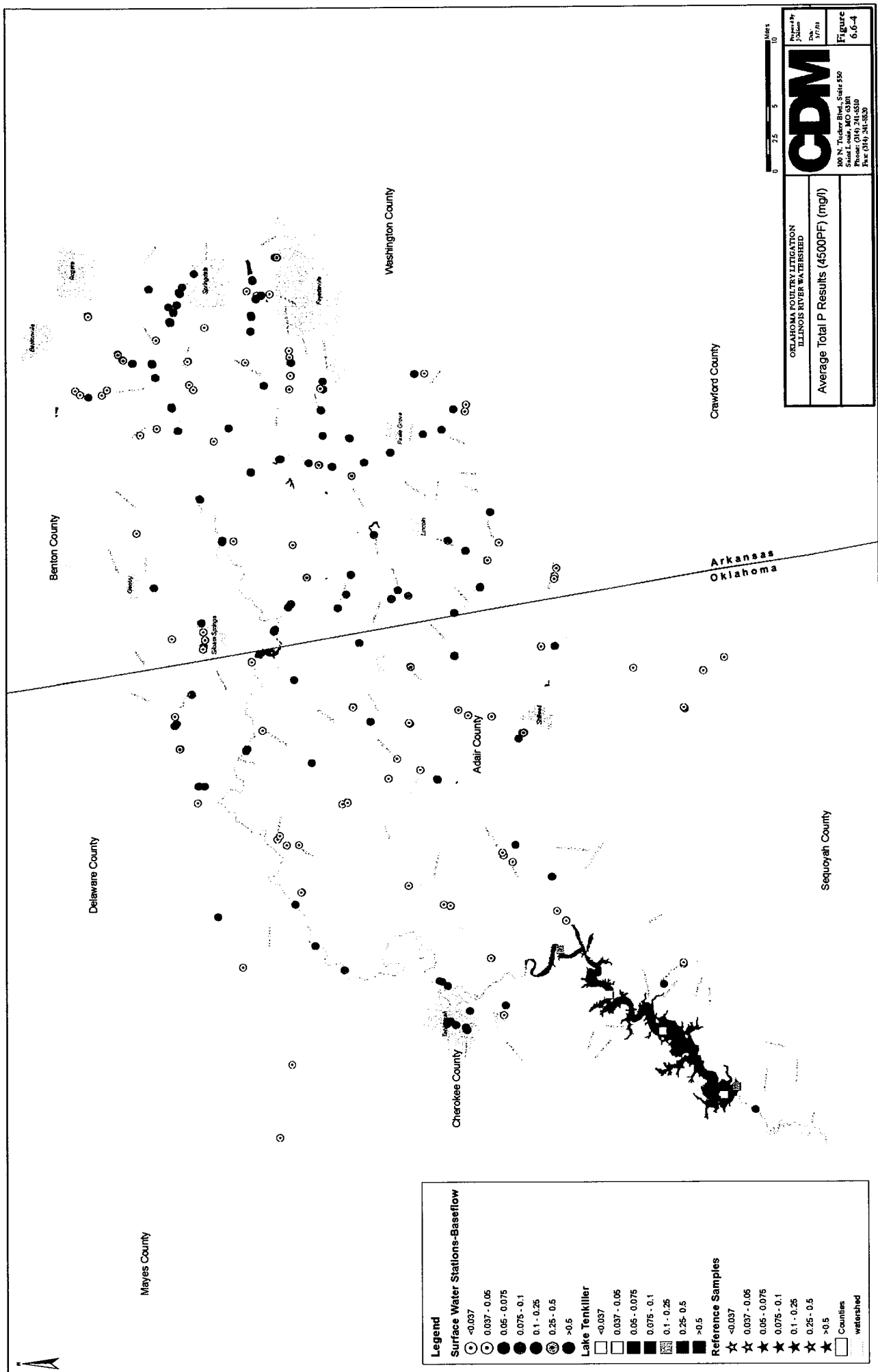

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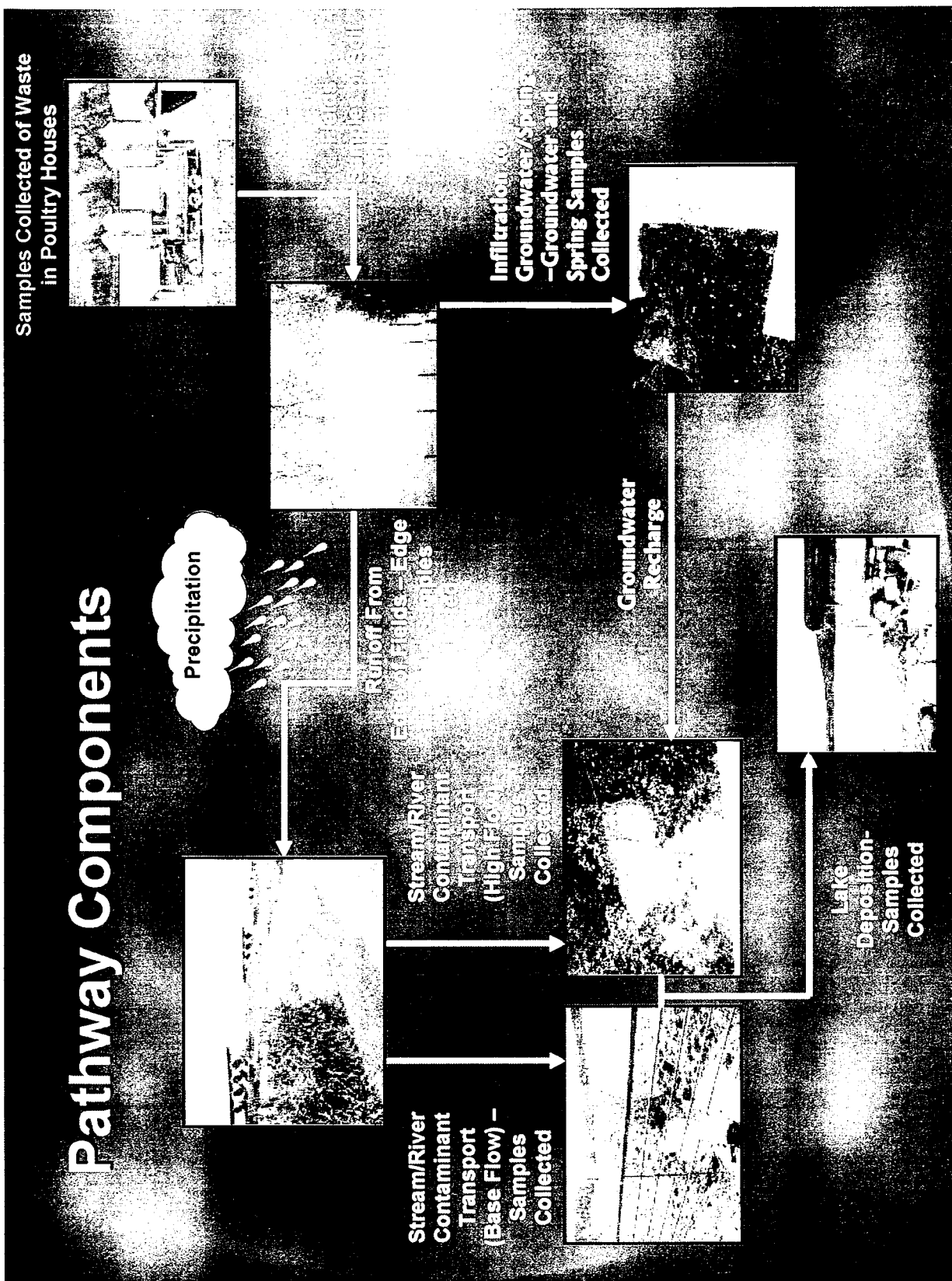
Roger L. Olsen, Ph.D.











**Figure 6.5-1**  
Environmental Pathway Components

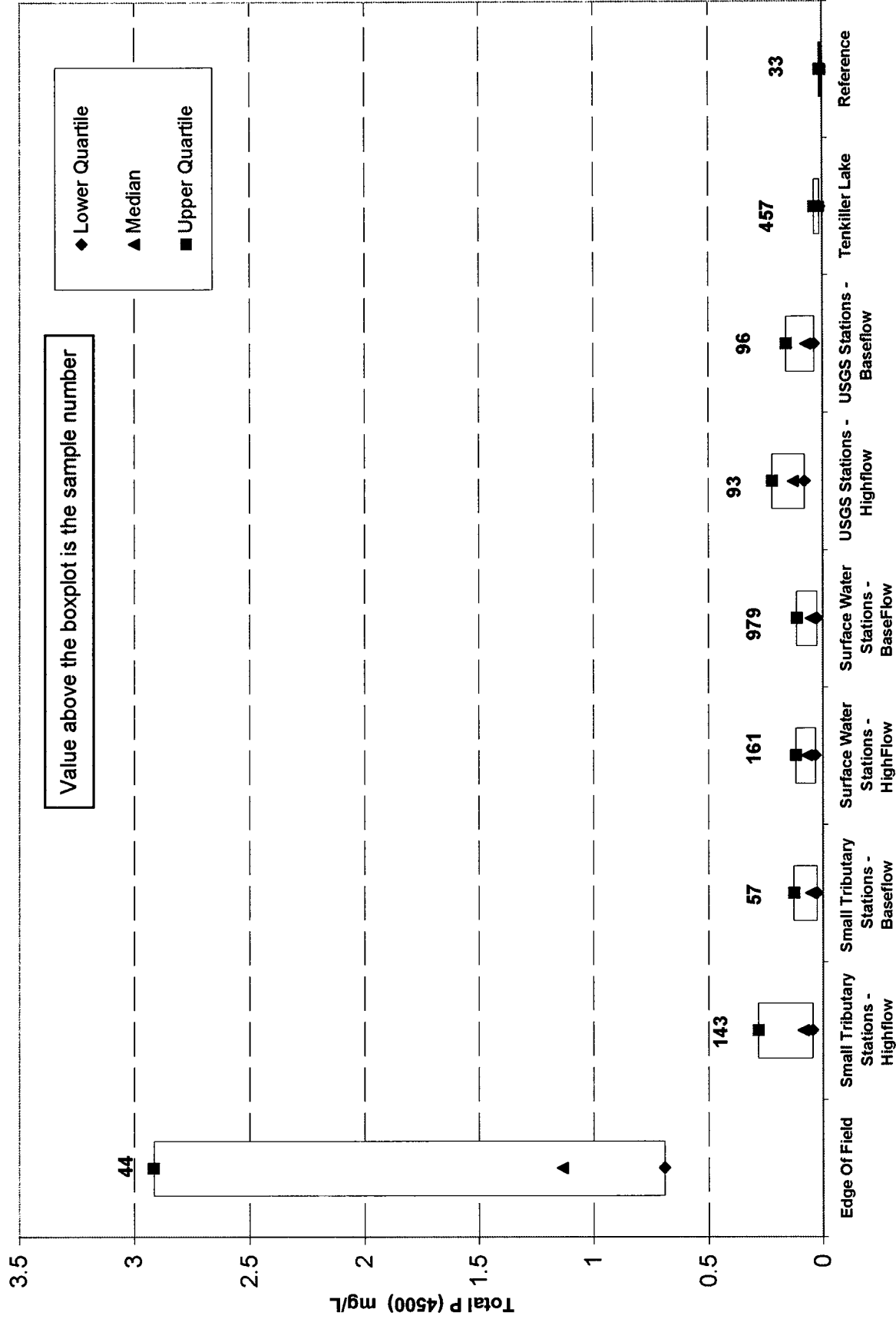


Figure 6.5-2  
Comparison Between Surface Water Environmental Components - Total P (4500) (mg/L)

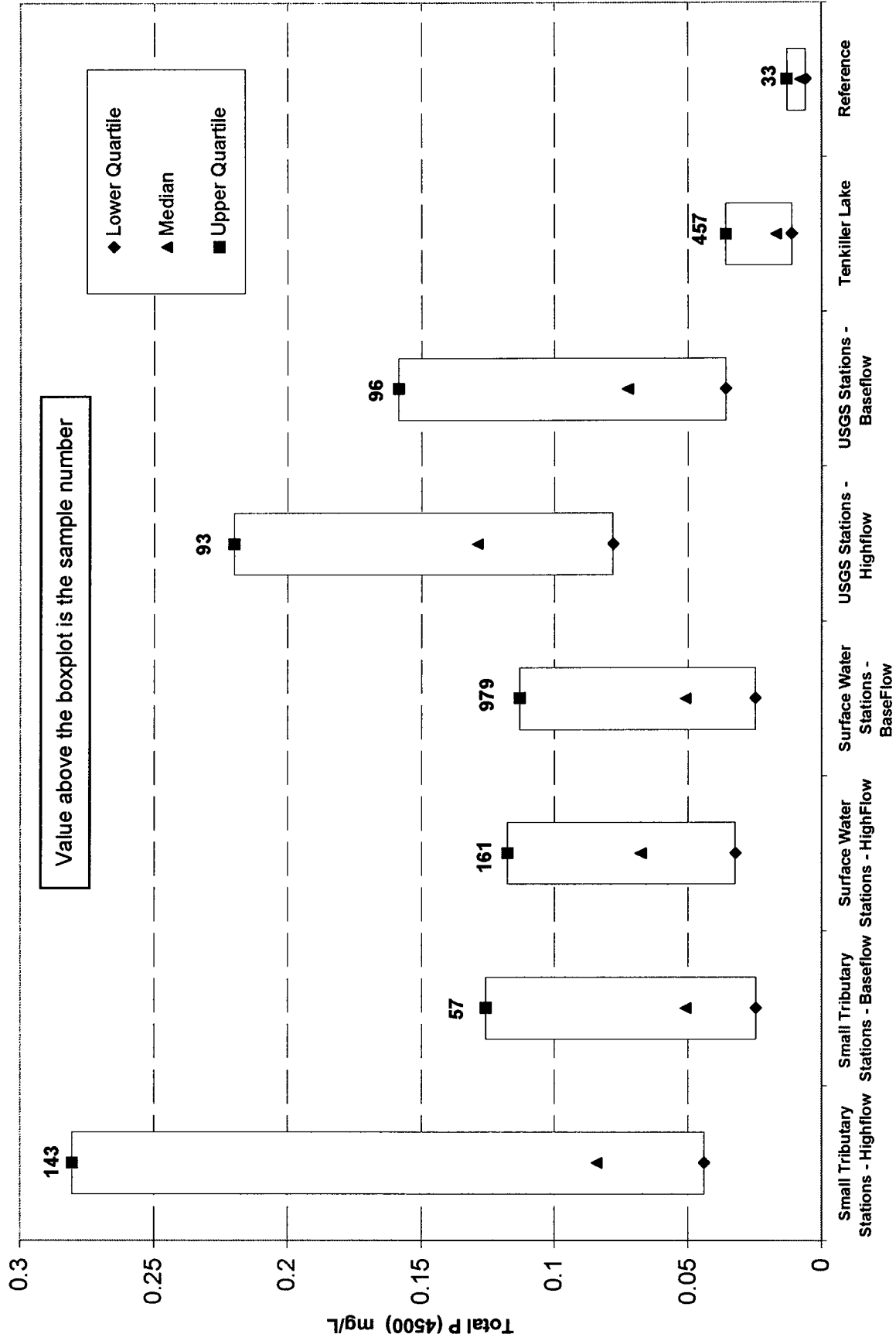


Figure 6.5-3  
Comparison Between Surface Water Environmental Components - Total P (4500) (mg/L)

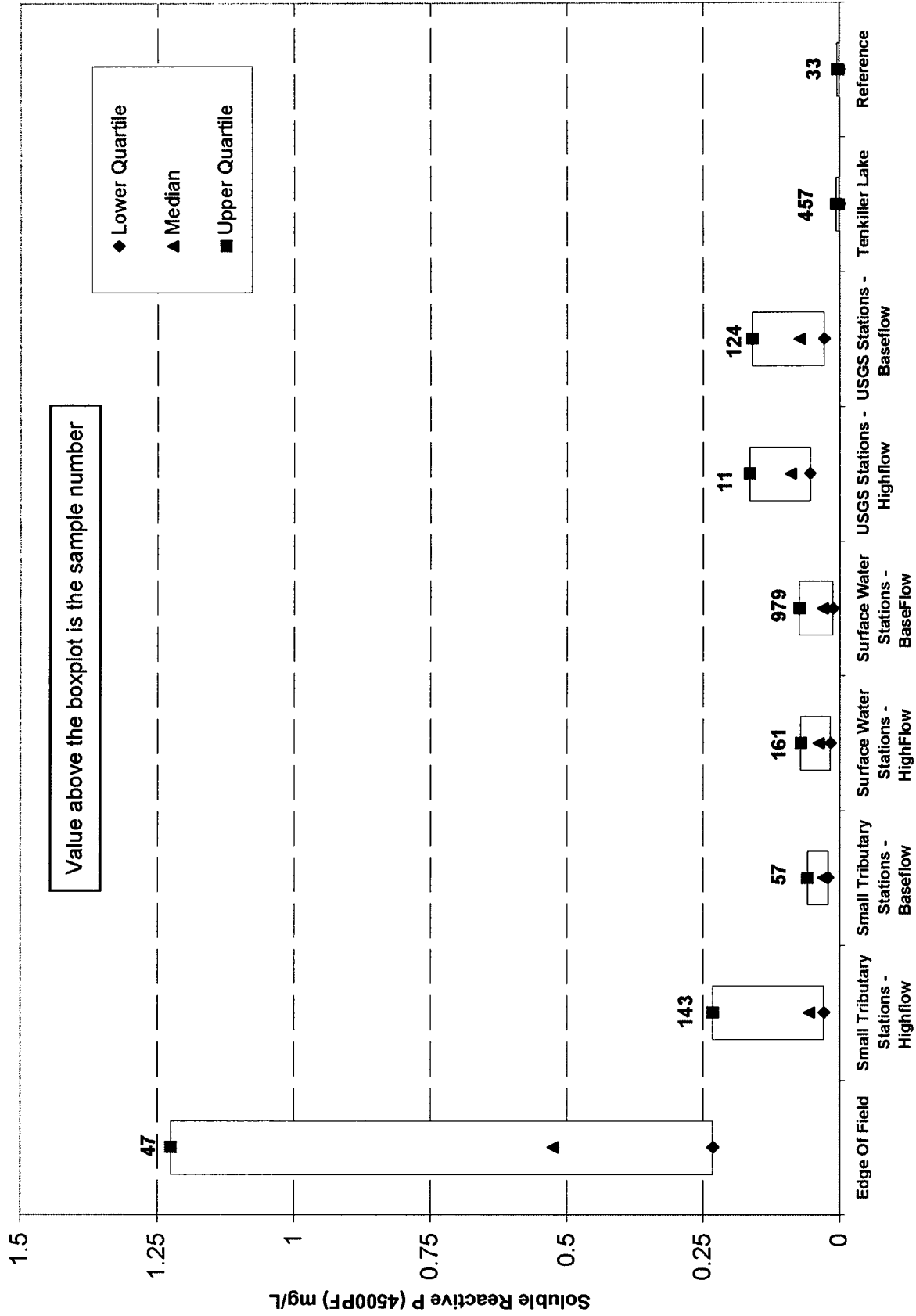


Figure 6.5-4  
Comparison Between Surface Water Environmental Components - Soluble Reactive P (4500PF) (mg/L)

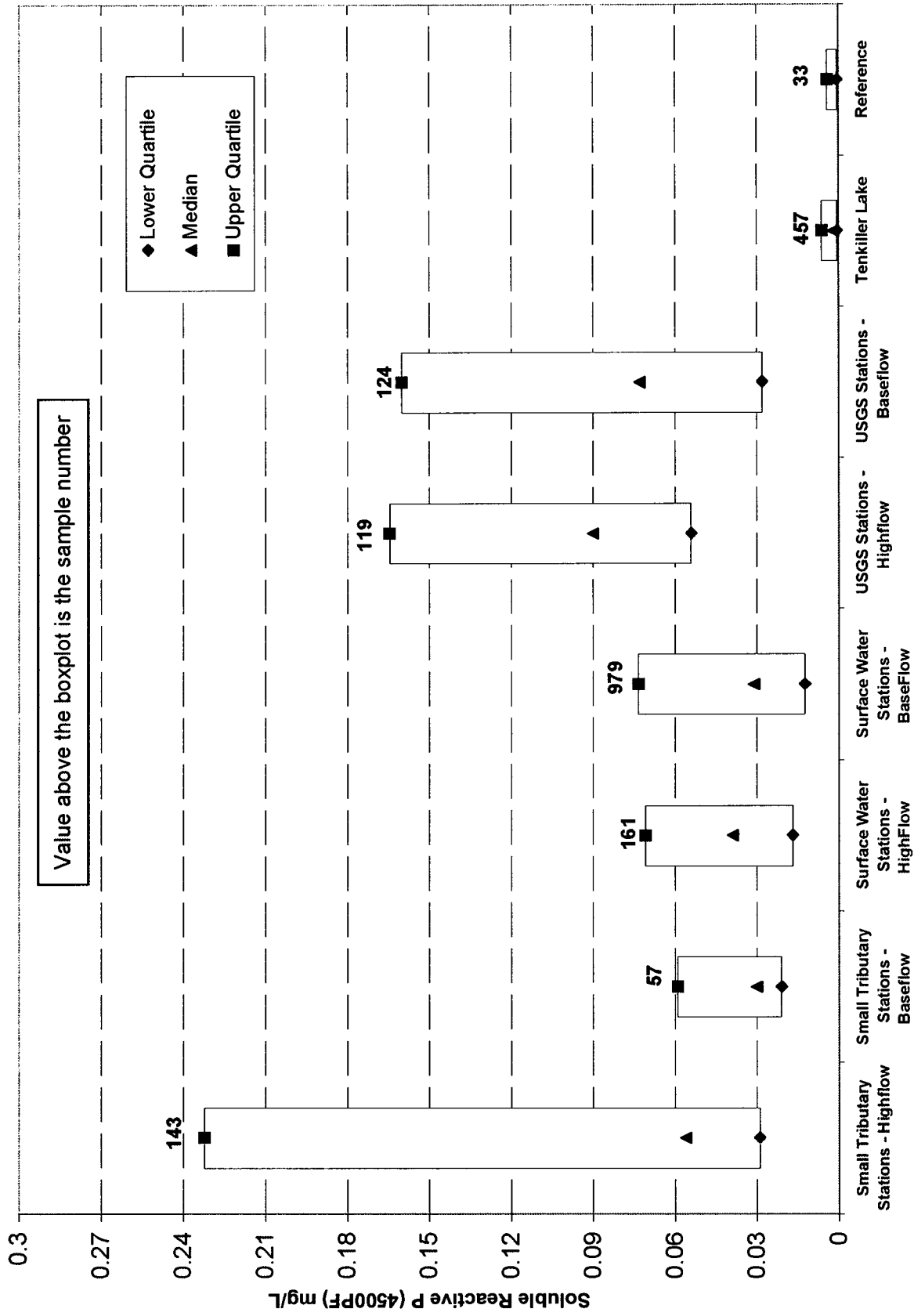


Figure 6.5-5  
Comparison Between Surface Water Environmental Components - Soluble Reactive P (4500PF) (mg/L)

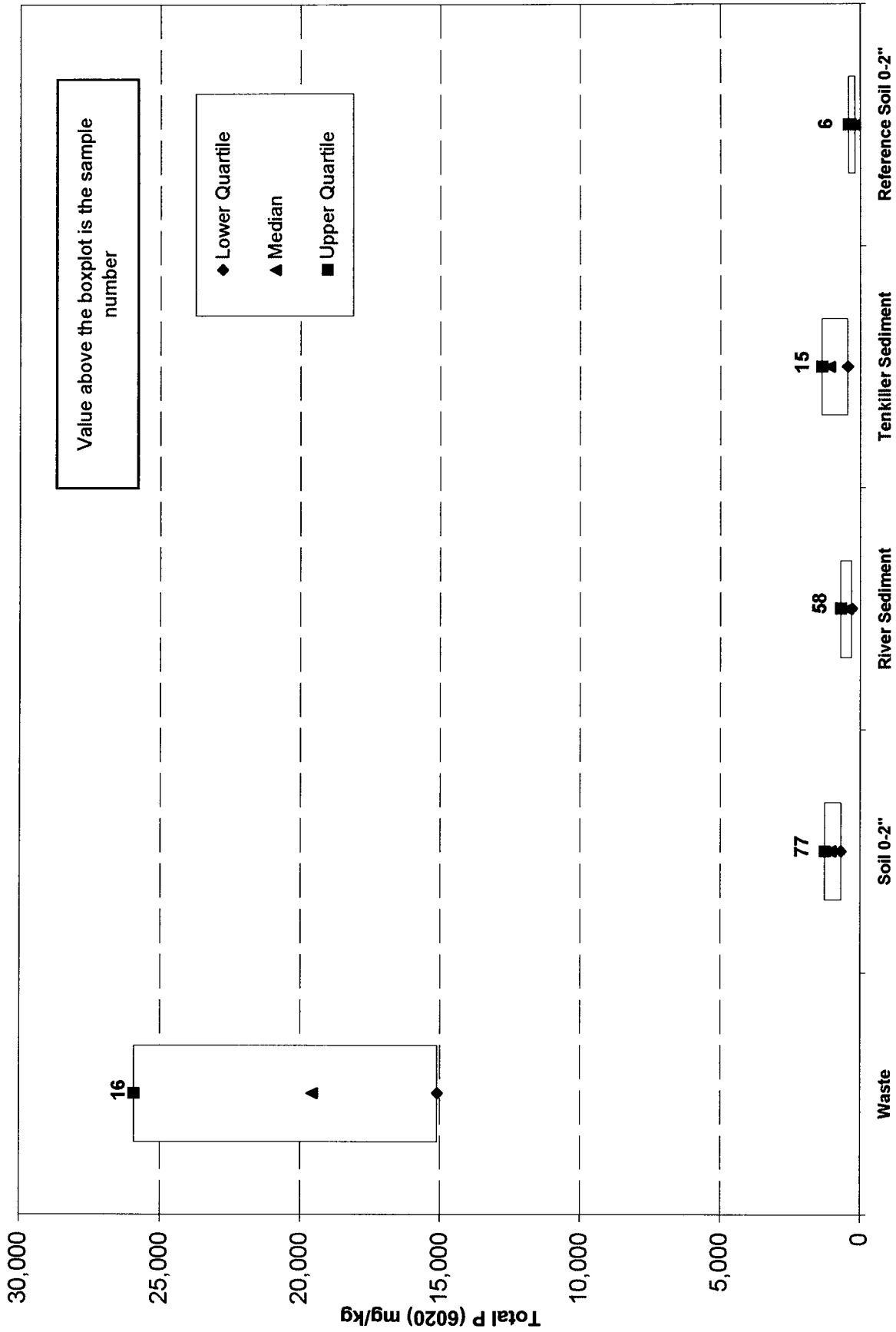


Figure 6.5-19  
Comparison Between Solids Environmental Components - Total P (6020) (mg/kg)

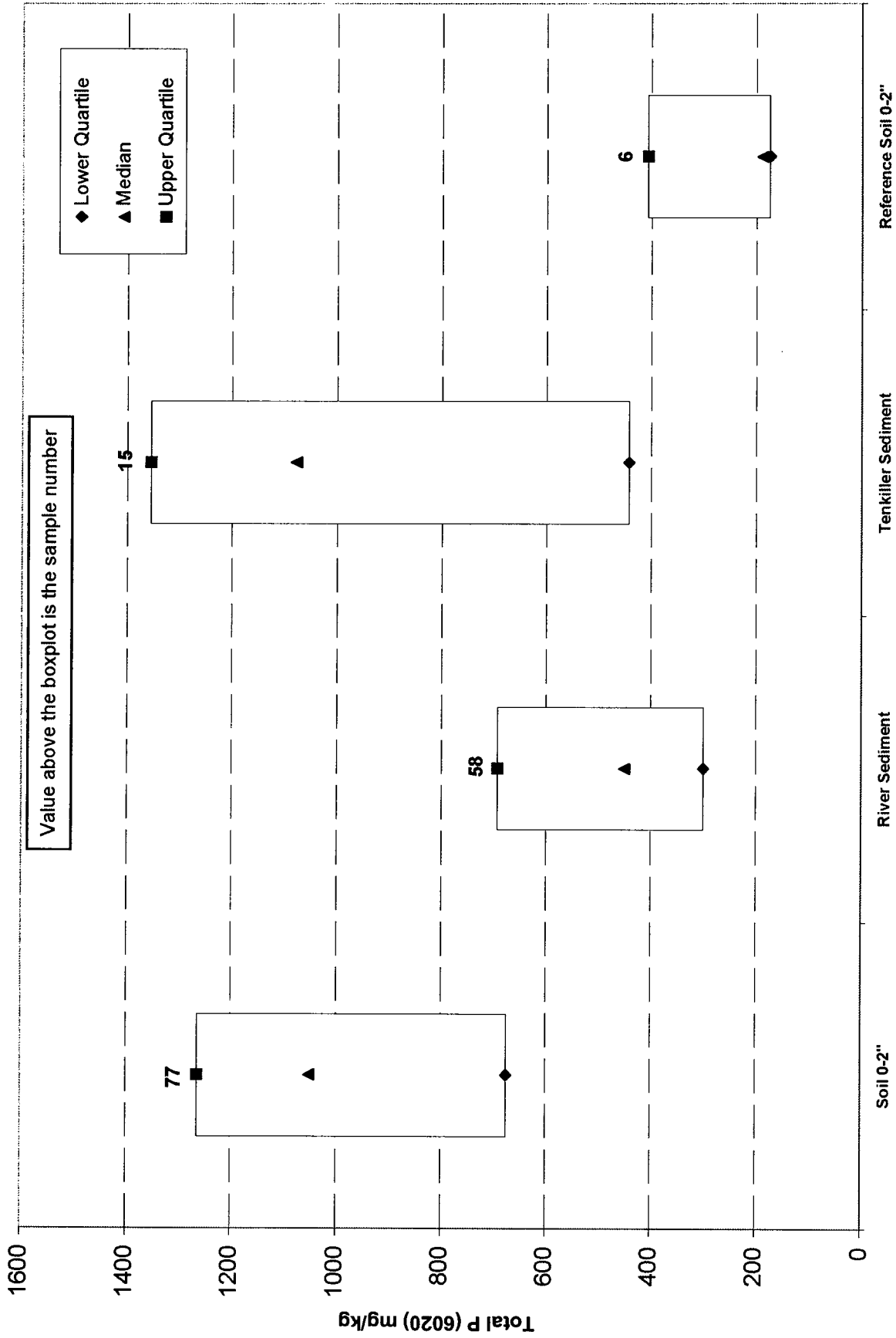
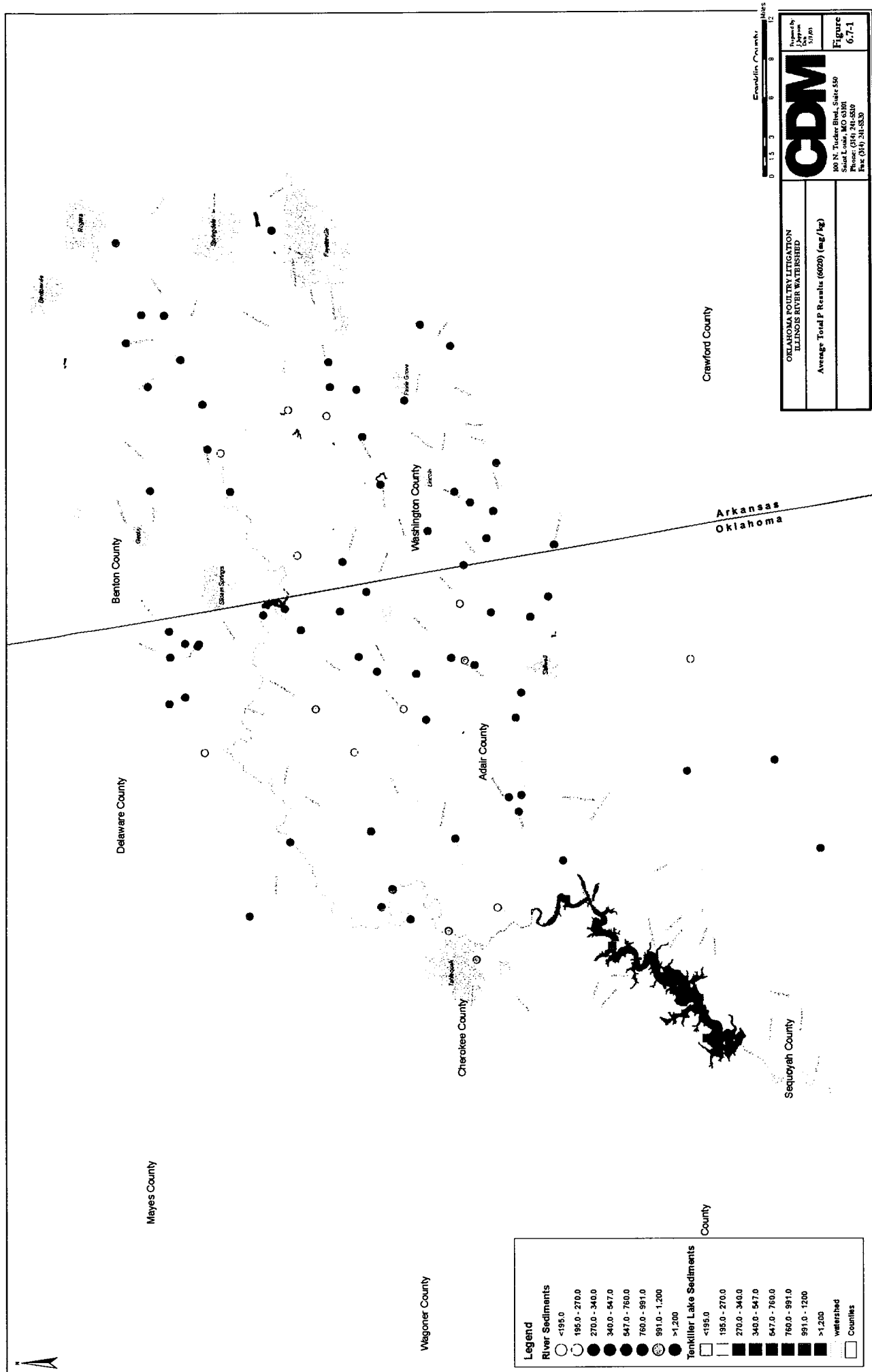


Figure 6.5-20  
Comparison Between Solids Environmental Components - Total P (6020) (mg/kg)



Q. And did you do a similar analysis for groundwater?

A. Yes, I did.

Q. And what did you find?

A. Again, for those samples of groundwaters that had bacteria and for which I had enough parameters to do the PCA evaluation, *67 percent* of those samples had poultry waste in them.

Q. Again, what does that mean in plain terms?

A. It means that *over two-thirds* of those samples that had exceedances that I could evaluate had poultry waste contamination.

Olsen Testimony, Tr. Vol. IV at 827:6-828:11 (emphasis added) (Aplt. App. 27, Vol. VI, at 2083-84).

The State's experts were not alone in these conclusions that land disposal of poultry waste in the IRW may and, in fact, does present a threat to human health. Indeed, a string of findings by research scientists and government agencies were in complete harmony with and buttressed the State's experts' conclusions. *See* State's Exhibit 399 (Aplt. App. 35, Vol. VIII, at 2918); State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930). For example:

- The Natural Resource Conservation Service stated in 1991 that "[n]utrients and bacteria from animal waste applied to fields and in inadequate domestic septic systems could potentially contaminate the [Boone] aquifer." *See* Tolbert Testimony, Tr. Vol. I at 81:8-82:4 (Aplt. App. 25, Vol. V, at 1392-

93); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930). The Boone aquifer is the aquifer that underlays the IRW. *See* Tolbert Testimony, Tr. Vol. I at 82:5-7 (Aplt. App. 25, Vol. V, at 1393).

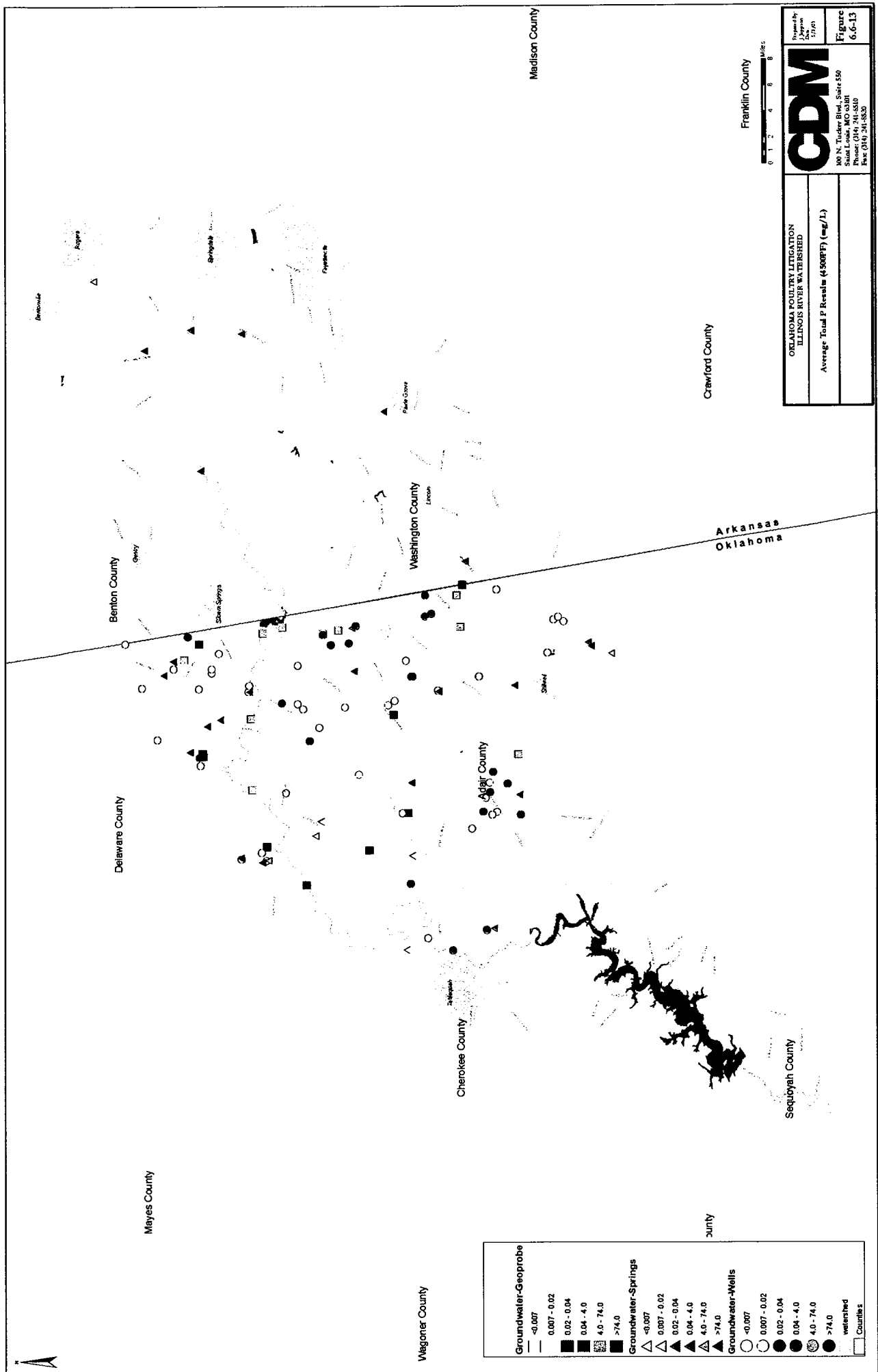
- The United States Geological Survey stated in 1995 that "[p]roduction of large numbers of poultry, cattle and swine in northwestern Arkansas and increasingly in southwestern Missouri and northeastern Oklahoma is contributing to elevated nutrient and bacteria concentrations in streams." *See* Tolbert Testimony, Tr. Vol. I at 82:8-14 (Aplt. App. 25, Vol. V, at 1393); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930).
- The Arkansas Natural Resources Commission stated in 1996 that "runoff water from areas where manure is improperly managed can carry excessive amounts of nutrients, bacteria and sediments." *See* Tolbert Testimony, Tr. Vol. I at 82:15-83:3 (Aplt. App. 25, Vol. V, at 1393-94); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930).
- The United States Geological Survey stated in 2001 that "[r]ecent sampling of the Illinois River indicated that fecal coliform bacteria counts in the Illinois River downstream from what's Oklahoma exceed the primary contact recreation standard. . . . If counts continue to exceed these standards, the recreational status of the Illinois River would be threatened, resulting in a loss of revenue to the local economy." *See* Tolbert Testimony,

Tr. Vol. I at 83:4-11 (Aplt. App. 25, Vol. V, at 1394); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930).

- The Office of the Oklahoma Secretary of the Environment stated in 2003 that "[e]xcess phosphorus and bacteria currently impair the Illinois River, Flint Creek and Barren Fork." *See* Tolbert Testimony, Tr. Vol. I at 83:12-18 (Aplt. App. 25, Vol. V, at 1394); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930).
- The Arkansas Water Resource Center stated in 2005 that "the spreading of poultry litter on fields is a common practice in this area. If *E. coli* from animal manures infiltrates the aquifers via surface runoff, the water supply may become contaminated. . . . The survival of fecal coliform bacteria, including *E. coli*, in these environments over extended periods highlights a continuing human health hazard associated with consumption of non-treated water from wells, streams and springs from the mantled karst of the Ozark region." *See* Tolbert Testimony, Tr. Vol. I at 84:1-10 (Aplt. App. 25, Vol. V, at 1395); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930).
- The United States Department of Agriculture stated in 2007 that "[p]hosphorus and pathogenic bacteria now impair many of the area streams, including the Illinois River. Non-point source impacts affecting waters in this segment are primarily from pastureland that is used for application of

poultry litter as fertilizer." *See* Tolbert Testimony, Tr. Vol. I at 85:9-24 (Aplt. App. 25, Vol. V, at 1396); & State's Exhibit 442 (Aplt. App. 47, Vol. VIII, at 2930).

Despite all this evidence (as well as other testimonial and documentary evidence) establishing that the land disposal of poultry waste may and does present real and immediate risks to human health, on September 29, 2008, the District Court denied the State's motion for preliminary injunction in a seven-page opinion and order. *See* Opinion and Order, 9/29/08 (Aplt. App. 23, Vol. IV, at 1353). The opinion and order contained no reference to or application of the RCRA liability standard and no detailed factual findings or consideration of evidence regarding the risks posed by the Poultry Integrators' disposal practices, but rather simply concluded that "[t]he State has not yet met its burden of proving that bacteria in the waters of the IRW are caused by the application of poultry litter rather than by other sources, including cattle manure and human septic systems." *See id.* (Aplt. App. 23, Vol. IV, at 1353). Additionally, after twice admitting into evidence the testimony and conclusions of Drs. Harwood and Olsen concerning the PCR and PCA lines of evidence, *see* Opinion and Order, 5/5/08 (Aplt. App. 22, Vol. IV, at 1350) & Opinion and Order, 9/29/08 (Aplt. App. 23, Vol. IV, at 1353), the District Court inexplicably proceeded to conclude that "the testimony and conclusions of expert witnesses Harwood and Olsen presented at the hearing are not sufficiently



In the matter of

State of Oklahoma, ex rel., A. Drew Edmondson in his capacity as Attorney General of  
the State of Oklahoma, and Oklahoma Secretary of the Environment, C. MILES  
TOLBERT, in his capacity as the Trustee for Natural Resources for the State of  
Oklahoma, Plaintiffs

v.

Tyson Foods, Tyson Poultry, Tyson Chicken, Inc., Cobb-Vantress, Inc., Aviagen, Inc.,  
Cal-Maine Farms, Inc., Cargill, Inc., Cargill Turkey Products, LLC, Georges, Inc.,  
George's Farms, Inc., Peterson Farms, Inc., Simmons Foods, Inc., and Willowbrook  
Foods, Inc.  
Defendants.

CASE NO. 05-CV-329-GFK-SAJ

in the United States District Court  
for the Northern District of Oklahoma

Expert Report

of

Roger L. Olsen, Ph.D.  
CDM  
555 17<sup>th</sup> Street, Suite 1100  
Denver, CO 80202

Cotter Dolomite of Ordovician age are exposed at the surface. The Burgen Sandstone and Cotter Dolomite are part of the underlying Roubidoux aquifer.

In Oklahoma, the Boone was among the four bedrock aquifers considered highly vulnerable to surface contamination because it contains karst features such as caves, sinkholes, and disappearing streams, which provide direct conduits for precipitation and runoff to transport contaminants to the water table.

Recharge to the Boone hydrogeologic basin is almost entirely from direct infiltration of precipitation. The factors that make the outcrop of the Boone Formation favorable to groundwater recharge also make it vulnerable to contamination. Because soil and subsoil in the Ozarks is thin, near-surface faults and fracture systems are common, and dissolution of the carbonate rocks is widespread, precipitation can quickly infiltrate the unsaturated zone.

Given the geology and hydrogeology, constituents of land disposed poultry waste run off fields into surface water and infiltrate through geologic media and contaminate groundwater. The poultry waste constituents are poorly attenuated during runoff and infiltration. Poultry waste is disposed on fields within the IRW by simple broadcast spreading. The poultry waste is not mechanically incorporated into soils. As a consequence, both soluble and particulate fractions of this material are readily available for transportation through the agency of rainfall. When rain interacts with poultry waste, some of the material goes into solution. This dissolved material can then travel with the water as it moves downward through the soil and vadose zone to pollute the groundwater. Additionally, if sufficient rainfall occurs in a short enough period of time, runoff is produced (i.e. not all of the water can be taken up by the soil and it runs off the field). The dissolved material derived from the poultry waste will also move with the runoff and pollute surface water. Further, this runoff water can also carry particles of poultry waste that will pollute surface water, stream sediments and lake sediments. Because pores can be large in karst, particles can also be transported through the groundwater in karst aquifers. Both runoff and groundwater eventually end up in surface streams that flow to Lake Tenkiller. Thus pollution of the surface of the ground by the disposal of poultry waste as practiced within the IRW results in the pollution of surface water, ground water, stream sediments and lake sediments.

## 6.4 Sources of Contamination

### 6.4.1 Chemical and Bacterial Characteristics of Wastes

Table 6.4-1 provides the chemical and bacterial composition of poultry waste and cattle manure (solid samples). Tables 6.4-2a and 6.4.2b provide the chemical and bacterial composition of waters containing various waste sources including edge of field samples, synthetic leachates of poultry waste, synthetic leachates of cattle manure, cattle-influenced springs, effluent samples from WWTPs, and surface waters influenced by WWTP effluent in the IRW. Table 6.4-3 provides a comparison of the chemical and bacterial compositions of the poultry waste and cattle manure. Table 6.4-4 provides a comparison of the chemical and bacterial compositions of the

synthetic leachates of poultry waste and cattle manure. Table 6.4-5 provides a comparison of the chemical and bacterial compositions of waters containing various waste sources including edge of field samples, cattle impacted springs and effluent samples from WWTPs in the IRW. Comparisons in Tables 6.4-3, 6.4-4 and 6.4-5 are based on providing a multiplier (or factor by which the contaminants and concentrations are compared – see next section.)

#### *Solid Wastes*

Table 6.4-1 provides the chemical and bacterial composition of 16 composite waste samples collected from IRW poultry houses. The table also provides the chemical and bacterial composition of 10 samples of cattle manure collected in the IRW from fields with no documented application of poultry waste. Table 6.4-3 is a comparison of the chemical and bacterial composition listed in Table 6.4-1 between the poultry waste and the dry manure and the poultry waste and the fresh manure. The poultry waste was chosen as the baseline values for the following comparison. A factor (ratio) was calculated by dividing the value (concentration) of each constituent in the poultry waste by the value (concentration) for the same constituent in either the fresh or dry cattle manure. If the resulting factor is above one, the parameter is found in greater concentration in the poultry waste than the manure. If the resulting factor is below one, the parameter is found in greater concentration in the cattle manure than the poultry waste.

As shown in Table 6.4-3, the concentrations of the following parameters are very significantly higher (10-100 times greater) in poultry waste compared to fresh cattle manure: sulfate (water soluble), arsenic, chloride (water soluble), nickel, copper, nitrate (water soluble), potassium, vanadium, and sodium. Several parameters were significantly higher (five to ten times greater) in the poultry waste than in the fresh manure (sulfate (water soluble), nitrate (water soluble), sodium, silver, and zinc). Total solids, total phosphorus, ammonium (water soluble), chromium, aluminum, iron, calcium, manganese, potassium, vanadium, soluble salts were also found in greater concentrations (two to five times greater) in the poultry waste than in the fresh cattle manure.

As shown in Table 6.4-3, the concentrations of the following parameters are very significantly higher (10-100 times greater) in poultry waste compared to dry cattle manure: arsenic, and copper. Several parameters were significantly higher (five to ten times greater) in the poultry waste than in the dried manure (total phosphorus, ammonium (water soluble), chromium, silver, zinc, and soluble salts). Higher concentrations (two to five times greater) of total solids, molybdenum, phosphorus (Mehlich-3), aluminum, iron, calcium, cobalt, manganese, lead, and magnesium, were observed in the poultry waste than in the dried cattle manure. The fresh cattle manure had significantly higher concentrations of E. coli, total coliform, fecal coliform, and mercury than the poultry waste.

In addition, the chemical and bacterial composition of poultry waste and cattle waste found in the literature is provided in Table 6.4 -1. Typically the concentrations

reported in the literature are similar to those measured for samples collected in the IRW.

#### *Water Samples*

Tables 6.4-2a and 6.4-2b provides the chemical and bacteria composition of waters containing edge of field samples (typically 2 potentially cattle-influenced samples and typically greater than 80 poultry-influenced samples), synthetic leachates of poultry waste (typically 2 samples) and cattle manure (typically 5 samples of fresh manure and 5 samples of dry manure), cattle-influenced springs (typically 2 samples) effluent samples from WWTPs (typically 3 samples), and surface waters influenced by WWTP effluent (typically 25 samples) in the IRW. Table 6.4-4 is a comparison of the average chemical and bacterial composition listed in Table 6.4-2 for the synthetic leachates at 20:1 ratio for the poultry waste (baseline) and the fresh and dried cattle manures using the same factor calculation described above. Table 6.4-5 is a comparison of the average chemical and bacterial composition listed in Table 6.4-2 between the poultry-influenced edge of field samples (baseline) and the potential cattle-impacted edge of field samples, effluent samples from WWTPs, and surface waters influenced by WWTP effluent in the IRW using the same factor calculation described above.

Comparison of Synthetic Leachates (Poultry and Cattle): As shown in Table 6.4-4, for the fresh cattle manure leachates, poultry waste was two to five times higher than cattle manure for magnesium, selenium, soluble reactive phosphorus, manganese, 17 $\alpha$ -estradiol, and total phosphorus (by methods 4500PF and 6020). Poultry waste was observed to be five to ten times higher than fresh cattle manure leachates for alkalinity, dissolved aluminum, dissolved chromium, dissolved cobalt, dissolved sodium, and dissolved solids. Poultry waste levels for chloride, dissolved arsenic, dissolved copper, dissolved iron, dissolved molybdenum, dissolved nickel, dissolved potassium, dissolved zinc, TKN, and total sulfate were greater than 10 times the levels in the fresh cattle manure leachates. The greatest difference (over 100 times greater in concentration) between the poultry waste leachates and the fresh cattle manure leachates were observed for dissolved copper. The fresh cattle manure leachates had higher concentrations of Estrone than the poultry waste leachates.

As shown in Table 6.4-4, for the dry cattle manure leachates, poultry waste was calculated to be between two and five times greater for magnesium, selenium, and soluble reactive phosphorus. Poultry waste leachates were observed to be five to 10 times greater than the dry manure leachates for dissolved chromium, dissolved cobalt, dissolved manganese, and total dissolved phosphorus (by methods 4500PF and 6020). Poultry waste concentrations were greater than ten times higher for levels of chloride, dissolved arsenic, dissolved copper, dissolved iron, dissolved molybdenum, dissolved nickel, dissolved potassium, dissolved zinc, TKN, total sulfate, alkalinity, dissolved aluminum, dissolved sodium, and total dissolved solids. The greatest difference (over 100 times greater in concentration) between the poultry waste leachates and the dry cattle manure leachates were observed for dissolved copper and 17 $\alpha$ -estradiol. The dried cattle manure leachates had no parameters that were found in significantly higher concentrations than in the poultry waste leachates.

Comparison of EOF Samples (average EOF for fields with poultry waste and average EOF for cattle): As shown in Table 6.4-5, the concentrations of the following parameters are very significantly higher (over a factor of 100) in poultry edge of fields (EOF) average compared to potential cattle EOF average: Estriol, Estrone, dissolved mercury, dissolved cobalt, dissolved arsenic. The poultry leachate had between 10 and 100 times the 17a-estradiol, 17b-estradiol, ammonia nitrogen, dissolved manganese, dissolved molybdenum, dissolved nickel, thallium (total and dissolved), Staphylococcus aureus, total calcium, total chromium, total coliform, total copper, total and total dissolved phosphorus (6020), and total sodium concentrations than the cattle manure EOF. Chloride, dissolved aluminum, antimony (total and dissolved), dissolved calcium, dissolved chromium, dissolved iron, potassium (total and dissolved), selenium (total and dissolved), dissolved sodium, E. coli, Enterococcus group, fecal coliform, soluble reactive phosphorus (4500PF), total arsenic, total cobalt, total and total dissolved phosphorus (4500PF), TKN, nitrate + nitrite, total molybdenum, total nickel, total sulfate, and total zinc were significantly higher in concentration in the poultry EOF than the cattle EOF (five to ten times more). The poultry EOF had two to five times higher levels of alkalinity, barium (total and dissolved), beryllium (total and dissolved), cadmium (total and dissolved), dissolved copper, dissolved lead, magnesium (total and dissolved), silver (total and dissolved), vanadium (total and dissolved), dissolved zinc, Salmonella species, TOC, total aluminum, total dissolved solids, total iron, total lead, and total manganese, than the cattle EOF. The average cattle EOF had no parameters that were found in significantly higher concentrations than in the poultry EOF.

Comparison of EOF (from field with poultry waste) and WWTP effluents: As shown in Table 6.4-5, the concentrations of the following parameters are significantly higher (over 100 times more) in poultry edge of field samples (EOFs) average compared to the wastewater treatment plant effluents (WWTP) average: dissolved arsenic, dissolved mercury, Enterococcus group, E. coli, fecal coliform, and total aluminum. Concentrations of dissolved cobalt, thallium (total and dissolved), Staphylococcus aureus, TOC, total arsenic, total barium, total chromium, total, coliform, total copper, total iron, total lead, total manganese, total phosphorus (6020), and total suspended solids were found in 10 to 100 greater concentrations in the poultry EOF than in the WWTP. Dissolved aluminum, antimony (total and dissolved), dissolved barium, selenium (total and dissolved), total dissolved phosphorus (6020), total phosphorus (4500PF), total nickel, total vanadium, and total zinc were five to ten times greater in poultry EOF than in the WWTP. In the poultry EOF, there were slightly higher levels of ammonium nitrogen, beryllium (dissolved and total) cadmium (dissolved and total), dissolved copper, dissolved lead, magnesium (dissolved and total), dissolved manganese, dissolved molybdenum, potassium (dissolved and total), dissolved zinc, Salmonella species, soluble reactive phosphorus (4500PF), total dissolved phosphorus (4500PF), TKN, silver (total and dissolved), and total calcium than in the WWTP. The concentrations of dissolved chromium, dissolved iron, dissolved vanadium, sodium (total and dissolved), total sulfate, and dissolved nickel were higher in the WWTP than in the poultry EOF.

Comparison of EOF and Surface Waters Impacted with WWTP effluents: As shown in Table 6.4-5, the concentrations of the following parameters are significantly higher (over 100 times more) in poultry edge of field samples (EOF) average compared to waste-water treatment plant impacted surface waters (WWTP-SW) average: Breviabacteria 16S rRNA, dissolved arsenic, dissolved cobalt, Enterococcus group, total iron, and total copper. Ammonium nitrogen, Campylobacter species, dissolved copper, manganese (dissolved and total), fecal coliform, TOC, total aluminum, total arsenic, total chromium, total coliform, E. coli, total dissolved phosphorus (6020), total phosphorus (4500PF and 6020), TKN, total lead, and total suspended solids were found to be 10 to 100 times greater in concentration in the poultry EOF than in the WWTP-SW. The concentrations of dissolved aluminum, antimony (total and dissolved), dissolved iron, selenium (total and dissolved), thallium (total and dissolved), soluble reactive phosphorus (4500PF), total cobalt, total dissolved phosphorus (4500PF), and total zinc were greater by 5 to 10 times in the poultry EOF than in the WWTP-SW. In the poultry EOF, concentrations of 17a-estradiol, 17b-estradiol, beryllium (total and dissolved), cadmium (total and dissolved), dissolved lead, magnesium (total and dissolved), molybdenum (total and dissolved), potassium (total and dissolved), silver (total and dissolved), dissolved zinc, Estriol, total barium, total nickel, total ortho-phosphorus (365.2), and total phosphorus (365.2 and 6010) were 2 to 5 times greater than those found in the WWTP-SW. The concentrations of chloride, conductivity, dissolved boron, sodium (total and dissolved), Estrone, nitrate+nitrite, Staphylococcus aureus, and total sulfate were higher in the WWTP-SW than in the poultry EOF.

Comparison of EOF and Cattle-impacted Springs: As shown in Table 6.4-5, the concentrations of the following parameters are significantly higher (over 100 times more) in poultry edge of field samples (EOF) average compared to cattle-impacted springs average: dissolved arsenic, E. coli, total aluminum, and fecal coliform. The poultry waste leachate had 10 to 100 times greater concentrations of ammonium nitrogen, dissolved cobalt, copper (total and dissolved), iron (total and dissolved), thallium (total and dissolved), Staphylococcus aureus, total coliform, total zinc, Enterococcus group, Estriol, Estrone, total chromium, TKN, total phosphorus (6020), and total suspended solids. Dissolved aluminum, antimony (total and dissolved), dissolved chromium, dissolved molybdenum, selenium (total and dissolved), dissolved zinc, total cobalt, and total manganese were found in five to ten times greater concentrations in the poultry EOF than cattle-impacted springs. The poultry EOF had significantly higher (two to five times greater) concentrations of 17a-estradiol, 17b-estradiol, beryllium (total and dissolved), cadmium (total and dissolved), dissolved manganese, total nickel, silver (total and dissolved), TOC, vanadium (total and dissolved), total dissolved phosphorus (6020), total lead, total phosphorus (4500PF), and Salmonella species than the impacted springs. Nitrate + nitrate, chloride, dissolved barium, dissolved calcium, dissolved lead, and dissolved magnesium were found in higher concentrations in the cattle-impacted springs than in the poultry EOF.

### *Summary of Waste Characteristics*

Based on the characteristic of sources of contamination presented in this section, the following observations can be made:

- The potential major sources of contamination in the IRW (cattle, poultry waste and WWTP discharge) have distinct compositions
- The poultry waste, poultry waste synthetic leachates and edge of field samples from fields with poultry waste have significantly higher concentrations of many contaminants including phosphorus, copper, zinc, total Kjeldahl nitrogen and potassium. The very high concentrations of contaminants in the poultry waste should results in observable concentrations in the environmental components of the IRW (waters and sediments).
- The distinct compositions of the sources should result in definitive signatures of contamination in the IRW is the sources are major contributor to the contamination.

### **6.4.2 Mass Balance Evaluations**

The major potential sources of surface water, groundwater and sediment contamination in the IRW are land disposal of poultry waste, cattle manure direct deposition on field and in rivers and waste water treatment plant direct discharge into the rivers. Dr. Bernard Engel's Expert Report and Dr. Chri Teaf's Expert Report discusses these various sources (Engel 2008 and Teaf 2008).

#### *Quantities of Waste*

Dr. Engel determined that between 354,000 and 477,000 tons of poultry waste is generated per year in the IRW. The amount of cattle manure generated per year in the IRW has also been estimated by Dr. Engel and is approximately 319,000 tons. The yearly discharge from WWTPs is approximately 30.0 million gallons of effluent per day (Engel 2008, based on 2003 to 2006 data). Discharge quantities are provided in Table 6.4-6

#### *Phosphorus Mass Balance*

Dr. Engel has also evaluated the amount of phosphorus from each major source in the IRW. He has determined poultry production is responsible for 76.2 percent of the annual phosphorus contribution in the IRW. Beef cattle in responsible for 1.7 percent and human population is responsible for 3.2 percent.

#### *Phosphorus Loads to IRW Rivers and Tenkiller*

Dr. Engel (Engel, 2008) has also evaluated the quantities of phosphorus released into the surface waters of the IRW from major sources. Dr. Engel has determined that between 432,000 to 500,000 lb/yr of phosphorus that enters the waters of the IRW results from poultry waste application to fields in the IRW. In addition, 90,155 lb/yr of phosphorus was attributed to point source discharges (based on 2003 to 2006). Some of the point source discharges are from poultry processing facilities. For cattle,

35,600 lb/yr of phosphorus are excreted in or near streams; however, most of this recycled phosphorus from poultry waste application.

#### *Bacteria Mass Balance*

Dr. Christopher Teaf has evaluated the amount of bacteria (fecal coliform) contributed to surface waters in the IRW. Overall, livestock accounts for 98.6 percent of the fecal coliform released to the IRW surface waters. Dr. Teaf has determined that of the livestock contribution, 41.4 percent is contributed by poultry waste and 44 percent percent is contributed by cattle.

#### *Mass Balance Based on Leaching Tests*

Leaching tests have been performed on both cattle manure and poultry waste. The tests were conducted using EPA synthetic precipitation leaching procedure (SPLP) method 1312 (SW846). The method is "designed to determine the mobility of both organic and inorganic analytes present in liquids, soils, and wastes." The test uses simulated (synthetic) rainfall (precipitation). Number 2 extraction fluid was used which represents rain west of the Mississippi River. A water to solids ratio of 20:1 is used (2 L of synthetic rain and 100 grams of waste). If required waste samples are disaggregated to size particles less than 10 mm in diameter. The dry cattle manure required particle size reduction. This process maximizes the amount of contaminants leached from the samples and in the case of older, dry cattle manure would not represent actual field conditions. However, the poultry waste is already a relatively fine particle sized material. Therefore, the leaching tests result in exaggerated concentration from dry cattle waste when compared to poultry waste that would be observed in the environment. The results of the leaching tests are presented and discussed in Section 6.4.1 (**Table 6.4-2a**).

In this section, the results of the SPLP tests were used to estimate relative maximum amounts of contaminants that could be leached from cattle manure and poultry waste.

As stated, **Table 6.4-2a** provides the chemical and bacteria composition of the leachates at a 20:1 ratio for the poultry waste, fresh cattle manure and dry cattle manure. The leachate values (reported in mg/L) were converted into the mass of potentially leachable material using the average yearly waste produced (both poultry and cattle). Yearly poultry waste masses range from 354,000 tons to 500,000 tons (as disposed) and yearly cattle waste average mass is 319,000 tons (dry weight). The quantity of poultry waste was converted to a dry mass by using the average solids content reported for the poultry waste samples from the IRW. The leachate concentration results were multiplied by the leachate liquid to solids ratio (20L:100g) and the dry waste quantities to determine the total mass (Kg) of each contaminant. **Table 6.4-7a** compares the potential "maximum" mass in leachates (water) for all contaminants in both cattle manure and poultry waste. The "low limit" is based on the lower limit of poultry waste determined by Dr. Engel (354,000 tons/yr) and the "high limit" is based upon his upper limit (477,000 tons/yr). For cattle, results of both fresh and dry manure were used. **Table 6.4-7b** compares the leachable masses of both poultry waste and cattle manure. A factor (ratio) was calculated by dividing the value

of the poultry waste mass values by the value for either the fresh or dry cattle manure mass values. If the resulting factor is above one, the contaminant is potentially contributed to the water of the basin in greater concentration by the poultry waste than the manure. If the resulting factor is below one, the contaminant is potentially contributed to the water of the basin in greater concentration by the cattle manure than the poultry waste. The manure mass is compared to both the upper and the lower limit of the poultry waste mass.

As shown in Table 6.4-7b, for the fresh manure mass, a factor between one and five was calculated (i.e., the leachable poultry mass is 1 to 5 times greater than the leachable cattle mass) for dissolved aluminum, dissolved calcium, dissolved magnesium, dissolved manganese, e. coli, enterococci, fecal coliform, N+N, and total coliform using both the high and low poultry limit. A factor between five and ten was observed (poultry mass 5 to 10 times greater than the cattle mass) in the fresh manure mass for alkalinity (high and low limit), dissolved sodium (low limit), soluble reactive phosphorus (high and low limit), total dissolved phosphorus (4500PF and 6020 for high and low limit), and total dissolved solids (low limit). A factor of greater than 10 was calculated in the fresh manure leachates for chloride, dissolved arsenic, dissolved iron, dissolved nickel, dissolved potassium, dissolved sodium (high limit), dissolved zinc, TKN, total dissolved solids (high limit), and total sulfate (high and low limit). The greatest difference (over 100 times greater in concentration) between the poultry waste mass and the fresh cattle manure mass was observed for dissolved copper. The fresh cattle manure mass had higher concentrations of TOC than the poultry waste mass.

As shown in Table 6.4-7b, for the dry manure mass, a factor between one and five was calculated for dissolved aluminum, dissolved calcium, dissolved magnesium (not high limit), e. coli, enterococci, fecal coliform, N+N, TOC, and total coliform using both the high and low poultry limit. A factor between five and ten was observed in the dry manure mass for dissolved magnesium (high limit), dissolved manganese (high and low limit), soluble reactive phosphorus (high and low limit), total dissolved phosphorus (4500PF and 6020 for high limit), and total dissolved solids (low limit). A factor of greater than 10 was calculated for the fresh manure leachates for alkalinity (high and low limit), chloride, dissolved arsenic, dissolved iron, dissolved nickel, dissolved potassium, dissolved sodium (low and high limit), dissolved zinc, TKN, total dissolved phosphorus (4500PF and 6020 for low limit), total dissolved solids (low and high limit), and total sulfate (high and low limit). The greatest difference (over 100 times greater in concentration) between the poultry waste mass and the fresh cattle manure mass was observed for dissolved copper. The fresh cattle manure mass had no constituent with higher concentrations of potentially leachable mass than the poultry waste mass.

As shown by the above calculations, the maximum potentially leachable mass of contaminants resulting from poultry waste is much greater than from cattle manure. As previously discussed, the cattle leachate values are probably exaggerated because of the required size reduction. Overall, assuming 90% dry and 10% fresh cattle

manure on actual fields, the cattle contribution to the total leachable mass of cattle and poultry wastes follows:

**Cattle Contribution to Leachable Parameter Masses**

Parameter	Units	Cattle Contribution (Poultry Low Limit)	Cattle Contribution (Poultry High Limit)
Copper	%	0.3	0.2
Potassium	%	1.8	1.3
Zinc	%	2.8	2.0
Enterococcus Group	%	41.7	33.6
Soluble Reactive P (4500PF)	%	13.0	9.6
Total Dissolved P (4500PF)	%	11.5	8.5
Total Dissolved P (6020)	%	10.1	7.4
Total Kjeldahl Nitrogen	%	5.3	3.8
Total Sulfate (SO <sub>4</sub> )	%	1.9	1.3
Arsenic	%	1.5	1.1
Iron	%	4.7	3.4
Manganese	%	14.4	10.6
Nickel	%	1.6	1.2
Sodium	%	2.9	2.1
Fecal Coliform	%	39.4	31.6
Total Dissolved Solids	%	5.7	4.1

These results are consistent with studies performed by researchers on actual field test plots. T.J. Sauer, et al (1999), used field test plots and simulated runoff to measure the relative quantities of selected contaminants for dairy cattle feces and urine and poultry waste. In the first treatment, all contaminants were higher in poultry runoff compared to dairy cattle runoff. Some of the information is summarized below by comparing the concentrations ratios and calculating a factor by which runoff from poultry waste was higher than runoff from cattle feces.

Contaminant	Factor Higher in Runoff from Poultry Waste Plots
Total N	8.4
Soluble Reactive P	17
Potassium	7
Copper	480
Zinc	1.1
Total Sulfur	2.6

The concentrations in the second treatment were not as high, but all contaminants (except iron and manganese) were still higher from the poultry waste. Sauer, et al, concluded that poultry plots, when compared to cattle plots, "provided at least six times the amount of each nutrient."

Test plots were also studied by M.L. Soupir, et al (2004). Transport plots (runoff water) plots with turkey waste resulted in between 1.2 to 1.7 times higher concentrations of dissolved phosphorus when compared to plots with “cowpies.” The total phosphorus amount was approximately the same.

### *Summary Observations*

Several observations can be made from the mass balance calculation in the previous sections. These include:

- The potential mass (or load) of contaminants into the IRW waters resulting from leaching cattle manure is significantly less than the potential mass of contaminants from poultry waste. For phosphorus, cattle manure would potentially contribute between 7.4 and 13 percent of the total mass from cattle and poultry waste combined. The potential mass contribution by cattle for copper, zinc and arsenic is very small ranging from 0.2 to 2.8 percent. The mass of major cations (potassium and sodium) potentially contributed by cattle is also very small ranging from 1.3 to 2.9 percent. The potential contribution by cattle for fecal coliform ranges from 32 to 39 percent.

As discussed, the calculated quantities (masses) are maximum quantities resulting from laboratory experiments. As shown by Dr. Engel’s calculations (Engel 2008), the actual quantities leached in the environment are substantial less. However, the tests were performed in the same manner on both poultry waste and cattle manure; therefore, the resulting values can be compared to each other and make determination of the relative contribution and amounts of contaminants. As previously stated, the cattle leaching test may over exaggerate the potential leachate concentrations due to disaggregation of the dry cattle manure. In addition, some poultry waste has been transported out of the IRW basin. According to Dr. Engel (Engel 2008), an average of about 8.8 percent of the poultry waste generated in the IRW was transported out of the basin between 2003 and 2006. This transport would not significantly decrease the relative amount of mass calculated in the above paragraph and would not change the overall conclusions.

## **6.4.3 Chemical Composition and Forms of Phosphorus**

### **6.4.3.1 Elemental Phosphorus**

Phosphorus is not found as a free element in the natural environment. It is found only as a constituent in terrestrial minerals, granite, in fertile soils, and in most meteorites in the form of Schriebersite (Budavari, 1996; Greenwood & Earnshaw, 1990). It is the eleventh most abundant element in Earth’s crust at a concentration of 1122 mg/kg (Greenwood & Earnshaw, 1990). Vital for growth and development in organisms, phosphorus is found in all cell protoplasm, DNA, bones, and teeth (Budavari, 1996; Greenwood & Earnshaw, 1990; Weast, 1970). Phosphorus plays an important role in energy transfer processes such as photosynthesis, muscle action, and nerve function (Greenwood & Earnshaw, 1990).

#### 6.4.3.2 Phosphorus in Poultry Diets

To ensure that the animals ingest the necessary amount of phosphorus to facilitate proper bone formation, energy utilization and general overall health, additional sources of phosphorus are included in poultry diets. The plant portion of poultry diet provides limited digestible phosphorus to the poultry. Phosphorus from animal products and mineral supplements are generally well utilized by the animal. There are several phosphorus additives available, including steamed bone meal, calcium phosphate dibasic from defluorinated phosphoric acid ( $\text{CaHPO}_4$ ), calcium phosphate monobasic ( $\text{Ca}(\text{HPO}_4)_2$ ), defluorinated phosphate ( $\text{PO}_4^{3-}$ ), ground Curacao phosphate rock, soft phosphate rock, sodium phosphate dibasic from furnaced phosphoric acid ( $\text{NaHPO}_4$ ), sodium phosphate monobasic ( $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$ ), and phosphoric acid ( $\text{H}_3\text{PO}_4$ ). The mono-dicalcium phosphates appear to be popular additives due to the more predicable and bioavailable phosphate concentration (NRC, 1994; Waldroup, 1999).

Dr. Fisher (Fisher, 2008) has reviewed the actual feed formulations used by integrators in the IRW. Feed formulations used by Tyson, Simmon's, Peterson's, Cargill, George's and Cal-Maine demonstrate that the Defendant's design and control the composition of feed provided to their poultry. In general, the feed formulations specified by the Defendants are dominantly comprised of corn and soybean meal, but frequently contain appreciable quantities of other grains and/or grain processing wastes as well as poultry by-product meal (poultry byproduct meal is made by grinding the rendered parts of poultry carcasses), feather meal, meat and bone meal, animal fat, including poultry fat, and various organic nutrients, including vitamins and amino acids. In nearly all cases, Defendants' feed formulations specify the addition of numerous chemicals (other than the materials specified in the foregoing list). The chemical compounds intentionally added to feeds by Tyson, Simmon's, Peterson's, Cargill, George's and Cal-Maine include: calcium phosphates, calcium carbonate, sodium chloride, potassium sulfate, zinc propionate, copper chloride, copper sulfate, arsenic in the form of 3-nitro-4-hydroxyphenylarsonic acid (a/k/a Roxarsone), selenium, trace minerals, vitamins and numerous antibiotic compounds. Therefore poultry feed contains numerous chemical elements, including, phosphorus, copper and zinc. Moreover, standard reference diets for chicks are specifically formulated using chemical compounds containing phosphorus, copper and zinc.

#### 6.4.3.3 Phosphorus in Poultry Waste

Variations in the amount of readily-soluble phosphorus throughout the literature can not be explained simply by differences in diet alone. The analytical methodology employed in the studying of phosphorus in manures differs among studies. The main differences are the pretreatment of the manure, the extraction solutions, the reaction times, and the number of replications. There seems to be little consistency on how the manures are handled, extracted and analyzed. Therefore, comparison among the different studies is difficult. (Turner & Lytem, 2004)

Animal manure is a source of available phosphorus for plants, but is often applied in excess of agrinomic needs (Johnson 2008). The organic phosphorus in animal manures

can be separated into two fractions: readily-soluble (water and  $\text{NaHCO}_3$  solutions) and poorly soluble ( $\text{NaOH}$  and  $\text{HCl}$  solutions). Compounds typically found in the readily-soluble fraction are soluble phosphate, phospholipids, DNA, and simple phosphate monoesters. The  $\text{NaOH}$  extractions of pasture-fed cattle had a predominance of phospholipids and RNA degradation products. Microbial-originated compounds can be a considerable component of phosphorus in some manures. The phytic acid is not readily bioavailable to organisms once it stabilizes in the soil. Turner and Leytem (2004) found, using the Hedley Fractionation method, that the readily-soluble percentage of extractable phosphorus was 31 percent in broiler litter and 54 percent in cow manure. (Celi & Barbaris, 2004; Lehmann, et al., 2005; Leytem, et al., 2002; Turner, 2004; Turner & Leytem, 2004; Turner, et al., 2002)

Phosphorus in animal manure is associated with calcium and magnesium as apposed to iron and aluminum (as seen in soils) in various studies. Turner and Leytem (2004), based on elemental concentrations of manure extracts, associated phosphorus with calcium and magnesium. Cooperband and Good were able to detect slightly soluble calcium phosphate minerals in poultry litter using scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy. This study also indicated that calcium and magnesium phylates have the ability to be quantitatively important in some manures. Fordham and Schwertmann (1997) utilized x-ray diffraction to detect magnesium and calcium phosphate minerals in dairy manure from solubility studies (Cooperband & Good, 2002; Fordham & Schwertmann, 1997; Turner & Leytem, 2004).

#### **6.4.3.4 Phosphorus in Poultry Waste Applied**

Phosphorus forms binuclear bridges with minerals containing OH surface groups and thus the soil solution concentrations of phosphorus are typically low. However, long-term manure application has manifested situations in which the soil binding sites are saturated and phosphorus mobilization has occurred. Due to long-term manure amendments, the capacity of soils to absorb additional phosphorus has been greatly decreased. Inorganic phosphorus appears to be retained in manured soils in greater proportion than organic phosphorus. Soluble phosphate, phospholipids, DNA, and simple phosphate monoesters compounds are weakly sorbed in the soil and have a high mobility through terrestrial and aquatic ecosystems. The high runoff potential of these organic phosphorus compounds make them environmentally significant even when present in small concentrations. The poorly soluble compounds strongly sorb to clay soils and react with metal oxides to form insoluble precipitates. The dominant insoluble phosphorus compound found in poultry litter and grain-fed cattle is phytic acid. (Behrendt & Boekhold, 1993; Eghball, et al., 1996; Heckrath, et al., 1995; Holford, et al., 1997; Hountin, et al., 2002; Lehmann, et al., 2005; Novak, et al., 2000; Turner & Leytem, 2004; Whalen & Chang, 2001)

Lehmann et al. (2005) found that there was a significant decrease in the retention of phosphorus to long-term poultry manured soils. An increase in the dissolved reactive phosphorus in saturated soils was observed as well as a decrease in the importance of dissolved unreactive phosphorus with an increase in manure application duration. This study also found that there was a greater mobility of organic phosphorus compared to inorganic phosphorus for short- and medium-term manure application.

For long-term poultry manure applications, the organic phosphorus may be converted to inorganic forms such as calcium phosphates. (Lehmann, et al., 2005)

A study by Lehmann et al. (2005) suggests that calcium phosphate dynamics are a likely control mechanism of the portion of available and mobile phosphorus found in soils amended with large amounts of manure. For low phosphorus soils (below 159 mg/kg), aluminum and iron phosphates were also found to influence the mobility of phosphorus by McDowell and Sharpley (2003). (Lehmann, et al., 2005; McDowell & Sharpley, 2003)

#### 6.4.3.5 Hazardous Substances in Poultry Waste

Assuming the list of Hazardous Substances and Reportable Quantities (table 302.4, 40 CFR § 302.4) includes not only the specific chemical listed but also chemical compounds, chemical forms and chemical combinations of the listed chemical, analyses of poultry waste and literature reports include many hazardous substances including:

- Ammonia (CASRN 7664417)
- Ammonia and Compounds
- Arsenic and compounds
- Cadmium and compounds
- Chromium and compounds
- Copper and compounds
- Lead and compounds
- Manganese compounds
- Nickel and compounds
- Nitric Acid (CASRN 7786-81-4)
- Nitrogen oxides
- Nitrosamines
- Phosphorus and compounds
- Phosphoric acid (CASRN 7664382)
- Polynuclear aromatic hydrocarbons
- Radionuclides
- Selenium and compounds
- Sodium and compounds
- Sulfuric acid (CASRN 7664939)
- Thiourea (CASRN 62566)
- Unlisted hazardous waste with characteristic of reactivity
- Zinc and compounds

The CAS Registry Number 7723140 refers to elemental phosphorus. This substance does not naturally exist in the environment. However phosphorus is present as compounds in the feed, poultry waste and poultry waste in soils mainly as phosphate ( $\text{PO}_4^{3-}$ ) compounds. As an environmental constituent dissolved in moisture or water (the mobile phase), the exact chemical composition of the phosphate will depend upon the pH of the water. At a neutral pH, the phosphate will exist as dissolved aqueous anions both:  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$ . At the same pH value, these chemical

forms and proportions of these chemical forms are identical to the chemical forms and proportions of the listed substance phosphoric acid.

## 6.5 Pathway Sampling Approach

The overall sampling approach was to collect and analyze water or solid materials (wastes, soils and sediments) in each major compartment (component) of the environment. The purpose of this approach was to document, if possible, the fate and transport of poultry associated contamination from its origin (land disposal of poultry waste) through each environmental transport step to the ultimate deposition in the sediments and water of Lake Tenkiller. Figure 6.5-1 illustrates each of the major environmental components. These include (in order from source to final location)

- Poultry waste from the poultry houses, upper right hand corner of Figure 6.5-1 (samples collected from the poultry houses in the IRW were called litter or facility, FAC, samples)
- Soils from fields on which land application of the poultry waste occurred (samples are called land application locations, LAL, samples)
- Water runoff from fields with waste as a result of precipitation (rainfall) events (samples are called edge of field, EOF, samples)
- Waters from small tributaries in watersheds in which poultry houses exist and waste disposal occurred (samples are called high flow station, HFS, samples)
- Ground water in shallow alluvial materials near streams that may be contaminated as a result of infiltration (rainfall moving through the soil) on waste applied fields (samples were collected using Geoprobe techniques and are called GP samples)
- Ground water from deeper geologic strata (samples were collected from existing homeowner wells and samples are called ground water, GW, samples)
- Water from springs that may represent contaminated groundwater resulting from infiltration on fields (samples are called spring, SPR, samples)
- Water from rivers within the IRW including both small and larger rivers (samples from larger streams at USGS stations are called USGS samples; samples from other locations, both large and smaller streams, are called river stations, RS, or biological stations on the rivers, RBS)
- Waters collected from streams during base flow conditions that represent groundwater recharge (samples from the small tributaries are call HFS-BF; however, all river samples have a designation indicating whether samples were collected during high flow or base flow)
- Waters from Lake Tenkiller (samples from Lake Tenkiller are designated lake, LK, samples)

- Waters from outside the IRW that are reference samples (samples are designated REF – also other designations, see Section 2.13)
- Sediments from rivers in the IRW (samples are designated sediments, SD, samples)
- Sediments from Lake Tenkiller (both grab and core samples were collected and are designated lake sediments, SEDLK or SDLK)

A number of major poultry waste constituents, or parameters, are found in each of the environmental components. Phosphorus (4500PF), total organic carbon (TOC), copper, zinc, potassium, enterococci, fecal coliform, e. coli, total coliforms, total Kjeldahl nitrogen (TKN), aluminum, iron, estrone, sodium, alkalinity, calcium, arsenic, magnesium, and total dissolved solids were contaminants selected to evaluate in each of the aquatic environmental components. Phosphorus (6020), total organic matter, copper, zinc, potassium, arsenic, calcium, estrone, e. coli, enterococci, fecal coliform, total coliforms, nitrogen, soluble salts, sodium, magnesium, sulfate (SO<sub>4</sub>), and phosphorus (water-soluble) were contaminants selected to calculate each the solids environmental components.

**Table 6.5-1** provides the average concentrations of the aquatic (water) contaminants of interest for surface waters: EOF, small tributaries (high- and base-flows), river surface water (high- and baseflows), USGS station samples (high- and base-flows), Lake Tenkiller samples, and reference samples. **Table 6.5-2** provides the average concentrations of the aquatic parameters of interest for groundwater including: edge of field samples (for comparison only), geoprobe samples, springs, and homeowner's wells. **Table 6.5-3** provides the average concentrations of the solids contaminants of interest for the poultry waste, soil (from fields with applied poultry waste) collected from 0-2 inches, river sediments, sediments from Lake Tenkiller, and reference soils. As shown, the poultry constituents (parameters of interest) are present in each of the environmental components in concentrations greater than background concentrations (compared to reference locations)

**Figure 6.5-2** through **Figure 6.5-11**, provide graphical representation of the data for the selected contaminants of interest for the surface water components. **Figures 6.5-2** and **6.5-3** provide graphical representation of the total phosphorus (4500PF) data. **Figures 6.5-4** and **6.5-5** provide graphical representation of the soluble reactive phosphorus data. **Figures 6.5-6** and **6.5-7** provide graphical representation of the enterococci data. **Figures 6.5-8** and **6.5-9** provide graphical representation of the TOC data. **Figures 6.5-10** and **6.5-11** provide graphical representation of the total potassium data. The samples for the different components have been separated in order to increase the clarity of the data (the first figure for each contaminant includes the EOF sample; the second figure does not.)

**Figure 6.5-12** through **Figure 6.5-18**, provide graphical representation of the data for the selected contaminants of interest for the groundwater components. **Figures 6.5-12** and **6.5-13** provide graphical representation of the total phosphorus (4500PF) data. **Figure 6.5-14** provides graphical representation of the soluble reactive phosphorus

data. Figure 6.5-15 provides graphical representation of the enterococci data. Figure 6.5-16 provides graphical representation of the TOC data. Figures 6.5-17 and 6.5-18 provide graphical representation of the total potassium data. The samples for the different components have been separated in order to increase the clarity of the data.

Figure 6.5-19 through Figure 6.5-26, provide graphical representation of the data for the different contaminants of interest for the solids components. Figures 6.5-19 and 6.5-20 provide graphical representation of the total phosphorus (6020) data. Figures 6.5-21 and 6.5-22 provide geographical representation of the total potassium data. Figures 6.5-23 and 6.5-24 provide graphical representation of the total copper data. Figures 6.5-25 and 6.5-26 provide graphical representation of the total arsenic data. The samples for the different components have been separated in order to increase the clarity of the data. These figures are discussed in the next section.

## 6.6 Indicator Chemicals in Water

The following paragraphs discuss several poultry related contaminants that are widely distributed and pervasive across the IRW. These contaminants include phosphorus, enterococci, total organic carbon, and potassium.

### 6.6.1 Distribution of Phosphorus through out the Basin – Water

Surface Water: Figures 6.6-1 through Figure 6.6-4 are spatial representations of the average concentration of total phosphorus (4500PF) for the various sampling locations. The majority of the locations had concentrations of total phosphorus (4500PF) that were greater than the Oklahoma water quality standard of 0.037 mg/L. Figure 6.6-3 indicates that the highflow surface water locations in Arkansas tended to have higher concentrations than those sampled in Oklahoma. As shown, phosphorus is widespread and pervasive throughout the entire basin with the average concentrations at most locations above 0.037 mg/L and above background concentrations. Particularly see Figure 6.6-4a which provides the results of soluble reactive phosphorus at 194 locations collected in August 2006 over a two week period.

Figure 6.5-2 and Figure 6.5-3 (introduced in previous section), indicate that the concentration of total phosphorus is highest in the poultry edge of field samples (EOF) and then decreases as the water moves through the various components. The majority of the concentrations of total phosphorus range from 0.6 mg/L to 3 mg/L for the EOF samples. The majority of the concentrations of total phosphorus for the other components are typically lower than 0.1 mg/L. As shown in Figure 6.5-4 and Figure 6.5-5, a very similar trend is seen with the soluble reactive phosphorus (SRP) with the majority of the concentrations for the EOFs ranging from 0.2 mg/L to 1.2 mg/L. The majority of the concentrations of SRP for the other components are typically lower than 0.1 mg/L.

Groundwater: Figure 6.6-13 is a spatial representation of the average concentration of total phosphorus (4500PF) for the various geoprobe, springs, and well stations. Phosphorus was found in each of these components, with higher concentrations found at the geoprobe and springs stations.